(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 350 640 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
05.02.1997 Bulletin 1997/06

(51) Int Cl.6: G01R 33/20, G01N 24/08, G01N 24/00, A61B 5/055, A61B 6/03

(21) Application number: 89110778.1

(22) Date of filing: 14.06.1989

(54) Nuclear magnetic resonance imaging apparatus with reduced acoustic noise

Kernspinresonanz-Abbildungsgerät mit reduziertem akustischem Rauschen

Appareil pour faire des images à résonance magnétique nucléaire avec un bruit acoustique réduit

(84) Designated Contracting States:
DE GB NL

(30) Priority: 14.06.1988 JP 144887/88

(43) Date of publication of application:
17.01.1990 Bulletin 1990/03

(73) Proprietor: KABUSHIKI KAISHA TOSHIBA
Kawasaki-shi, Kanagawa-ken 210 (JP)

(72) Inventor: Hirata, Haruhiko
Yokohama-shi Kanagawa-ken (JP)

(74) Representative: Lehn, Werner, Dipl.-Ing. et al
Hoffmann, Eitle & Partner,
Patentanwälte,
Postfach 81 04 20
81904 München (DE)

(56) References cited:
US-A- 4 636 729
US-A- 4 652 824
US-A- 4 774 486
US-A- 4 791 370

EP 0 350 640 B1

Description

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a nuclear magnetic resonance imaging apparatus for obtaining tomographic images of a body to be examined by utilizing a phenomenon of nuclear magnetic resonance.

Description of the Background Art

A nuclear magnetic resonance imaging apparatus provides an important means for analyzing atomic and electronic structures of matter or chemical compounds in a solid state and an organic chemistry research. Also, there are increasing uses in medical practice of the nuclear magnetic resonance imaging apparatus as a diagnostic device for obtaining tomographic images of arbitrary cross sections of a body to be examined, on a basis of such information as hydrogen distribution and spin relaxation times extracted by utilizing a nuclear magnetic resonance phenomenon.

A main portion of a conventional nuclear magnetic resonance imaging apparatus is shown in perspective view and in cross sectional view in Figs. 1 and 2, respectively. As shown, there is a main magnet 1 with bore for generating a static magnetic field, a hollow cylindrical outer shell 2 inside the bore which is connected to the main magnet 1 by supporting members 3, and a hollow cylindrical inner shell 7 inside the outer shell 2 which is connected to the outer shell 2 by ring members 8. Between the outer shell 2 and the inner shell 7, there is a gradient coil 21 for producing gradient magnetic field which is connected to the outer shell 2 by means of first gradient coil supporting member 4, a second gradient coil supporting member 5 and a support rubber 6.

As shown in Fig. 3, the gradient coil 21 comprises a X-coil 25, a Y-coil 27, and a Z-coil 29 wound around a coil core 23, each of which produces the gradient field in X-, Y-, and Z-directions, respectively. Also, as shown in Fig. 4, these X-coil 25, Y-coil 27, and Z-coil 29 are fixed on the coil core 23 by molding with a non-magnetic resin 24 with a relatively large Young's modulus, such as epoxy resin.

Each of these X-coil 25, Y-coil 27, and Z-coil 29 is provided with a separate power source, so that pulsed current for producing the gradient field can be applied separately when taking measurements.

However, as such gradient coil 21 is used in a presence of a very large static magnetic field generated by the main magnet 1 (typically between 0.22 to 1.5 Tesla), a considerable amount of electromagnetic force is exerted on each of these X-coil 25, Y-coil 27, and Z-coil 29, which gives vibrations of the gradient coil 21, which in turn causes the large acoustic noise.

Although in the nuclear magnetic resonance imaging apparatus of Fig. 1 the gradient coil 21 is confined inside a space formed by the outer shell 2, the inner shell 7 and the ring members 8 so as to muffle such acoustic noise, there still is a significant amount of vibration of the outer shell 2 caused by the vibration of the gradient coil 21 mediated through the air and through the first gradient coil supporting member 4, the second gradient coil supporting member 5 and the support rubber 6, as well as through the ring members 8. The noises may also be produced by the vibration of the coil core 23 and the resin 24.

Such acoustic noises can be quite disturbing to a patient to be examined who will be placed in a measurement space inside the inner shell 7.

Thus, in a conventional nuclear magnetic resonance imaging apparatus it has not been possible to eliminate all the disturbing acoustic noises originating from the vibration of the gradient coil 21.

For providing nuclear magnetic resonance equipment with significantly reduced noise generation, US-A-4 652 824 discloses locating a gradient coil in the vacuum between a main housing and a pipe of synthetic material.

US-4 636 729 discloses a nuclear magnetic resonance imaging apparatus as defined in the preamble of claim 1, further comprising parts that absorb air-borne sound.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a nuclear magnetic resonance imaging apparatus capable of considerably reducing the disturbing acoustic noises originating from the vibration of the gradient coil.

According to the present invention there is provided, in common with US-A-4 636 729, a nuclear magnetic resonance imaging apparatus, comprising: a main magnet for generating a static magnetic field in a measurement space in which a body to be examined is to be placed, gradient coil means for producing gradient magnetic fields over the static magnetic field, means for detecting signals from the body in the static and gradient magnetic fields due to a nuclear magnetic resonance phenomenon, and means for processing the detected signals so as to obtain tomographic images of the body at arbitrary cross sections.

The invention is characterised by: a vibration reducing sandwich structure which is located between the body and the main magnet and formed by a viscoelastic layer sandwiched between first and second sandwiching members, for reducing a vibration of the gradient coil means by a shearing deformation of the viscoelastic layer between the first and second sandwiching members.

Other features and advantages of the present invention will become apparent from the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view of a main portion of a conventional nuclear magnetic resonance imaging apparatus.

Fig. 2 is a cross sectional view of a main portion of the conventional nuclear magnetic resonance imaging apparatus of Fig. 1.

Fig. 3 is a perspective view of a gradient coil of the conventional nuclear magnetic resonance imaging apparatus of Fig. 1.

Fig. 4 is a perspective view of a coil core and a resin mold for the gradient coil of Fig. 3.

Fig. 5 is a perspective view of a main portion of the first embodiment of a nuclear magnetic resonance imaging apparatus according to the present invention.

Fig. 6 is a cross sectional view of a main portion of the nuclear magnetic resonance imaging apparatus of Fig. 5.

Figs. 7(A) and 7(B) are a graph of frequency characteristic of currents in a gradient coil and a diagram of force due to the currents, respectively, for the nuclear magnetic resonance imaging apparatus of Fig. 5.

Figs. 8(A) and 8(B) are a graph of frequency characteristic of vibrations in the gradient coil and a diagram of vibration modes of the gradient coil, respectively, for the nuclear magnetic resonance imaging apparatus of Fig. 5.

Figs. 9(A) and 9(B) are a graph of frequency characteristic of vibrations in a transmitter and receiver coil and a diagram of vibration modes of the transmitter and receiver coil, respectively, for the nuclear magnetic resonance imaging apparatus of Fig. 5.

Figs. 10(A) and 10(B) are graphs of frequency characteristic and positional variation of acoustic noises, respectively, for the nuclear magnetic resonance imaging apparatus of Fig. 5.

Fig. 11 is a cross sectional view of a main portion of a nuclear magnetic resonance imaging apparatus according to the first embodiment with which the experiments had been conducted.

Fig. 12 is a diagrammatic illustration of an inner shell of the nuclear magnetic resonance imaging apparatus of Fig. 11 for explaining a position where the measurement of the acceleration had been taken in the first experiment.

Fig. 13 is a graph of frequency characteristic of vibrations in an inner shell for both a conventional nuclear magnetic resonance imaging apparatus and the nuclear magnetic resonance imaging apparatus of Fig. 11, obtained by the first experiment.

Fig. 14 is an illustration of a cross section of a sandwich structure around viscoelastic layer in the nuclear magnetic resonance imaging apparatus of Fig. 5, for explaining shearing deformation arising in the sandwich structure.

Fig. 15 is a perspective illustration of the sandwich structure of Fig. 14, for explaining the reduction of acoustic noise achieved by the sandwich structure.

Fig. 16 is a graph of a dimensionless parameter ξ appearing in analysis of the reduction of acoustic noise achieved by the sandwich structure, as functions of two other parameters R_D and r_1 appearing in the same analysis for explaining the preferable conditions for the sandwich structure.

Fig. 17 is a perspective view of a main portion of the second embodiment of a nuclear magnetic resonance imaging apparatus according to the present invention.

Fig. 18 is a cross sectional view of a main portion of the nuclear magnetic resonance imaging apparatus of Fig. 17.

Fig. 19 is a diagrammatic illustration of an inner shell of the nuclear magnetic resonance imaging apparatus of Fig. 17 for explaining positions where the measurements of the acceleration had been taken in the second experiment.

Fig. 20 is another diagrammatic illustration of an inner shell of the nuclear magnetic resonance imaging apparatus of Fig. 17 for explaining positions where the measurement of the acoustic noise had been taken in the experiment.

Fig. 21 is a graph of the acceleration as a function of time measured at one location inside the measurement space in the second experiment.

Fig. 22 is another graph of the acceleration as a function of time measured at another location inside the measurement space in the second experiment.

Fig. 23 is a graph of acoustic noise level measured at various location inside the measurement space in the second experiment.

Fig. 24 is a perspective view of a main portion of the third embodiment of a nuclear magnetic resonance imaging apparatus according to the present invention.

Fig. 25 is a cross sectional view of a main portion of the nuclear magnetic resonance imaging apparatus of Fig. 24.

Fig. 26 is a cross sectional view of a main portion of the fourth embodiment of a nuclear magnetic resonance

imaging apparatus according to the present invention.

Fig. 27 is a cross sectional view of a main portion of the fifth embodiment of a nuclear magnetic resonance imaging apparatus according to the present invention.

Fig. 28 is a cross sectional view of a main portion of the sixth embodiment of a nuclear magnetic resonance imaging apparatus according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following description of the various preferred embodiments, those parts of a nuclear magnetic resonance imaging apparatus which are substantially equivalent to corresponding parts of the conventional nuclear magnetic resonance imaging apparatus of Figs. 1 and 2 will be given the same labels in the figures, and their explanations which can be found in the description of the background art above will in general be omitted to avoid unnecessary repetition.

Referring now to Figs. 5 and 6, there is shown a first embodiment of a nuclear magnetic resonance imaging apparatus according to the present invention.

In this first embodiment, there is provided a viscoelastic layer 9 made of polymer compounds such as butyl rubber, silicon rubber, polysulfide rubber, urethane rubber, fluoro rubber, polyvinyl chloride acetate, Neoprene rubber(Trade Name), and VEM(Trade Name) between a gradient coil 21 and a body to be examined which will be placed in a measurement space inside the bore of an inner shell 7. Such a viscoelastic layer 9, for example, can be formed in a middle of the inner shell 7, as shown in Figs. 5 and 6, by pouring liquid viscoelastic material into a hollow region prepared in the inner shell 7.

The insertion of this viscoelastic layer 9 for the purpose of reducing acoustic noises is based on the following analysis due to the present inventor, of the mechanism of generation and propagation of acoustic noises in a nuclear magnetic resonance imaging apparatus, which has been largely unknown heretofore.

It has been found that the propagation of acoustic noises takes place by a route of <force due to currents in the gradient coil 21> → <vibration of the gradient coil 21> → <vibration of the inner shell 7> → <acoustic noises>. Relevant data has been compiled which are shown in Figs. 7 to 10, of which Fig. 7(A) shows a graph of frequency characteristic of currents in the gradient coil 21 and Fig. 7(B) shows a diagram of force F due to the currents I in the gradient coil 21 along with the direction of the static magnetic field B generated by the main magnet 1, while Fig. 8 (A) show a graph of frequency characteristic of vibrations in the gradient coil 21 in terms of instantaneous acceleration and Fig. 8(B) shows a diagram of vibration modes of the gradient coil 21, i.e., extreme configurations of the gradient coil 21. Also, Fig. 9(A) shows a graph of frequency characteristic of vibrations in the inner shell 7 in terms of instantaneous acceleration and Fig. 9(B) shows a diagram of vibration modes of the inner shell 7, i.e. extreme configurations of the inner shell 7, while Figs. 10(A) and 10(B) show graphs of frequency characteristic and positional variation of acoustic noises along a central axis of the measurement space, respectively.

As can be seen from Figs. 7 to 10, the gradient coil 21 is fed with a pulsed current shown in Fig. 7(A) which shows increasingly small higher frequency components. Such currents in a presence of the static magnetic field B induces time varying forces F shown in Fig. 7(B) in the gradient coil 21, which causes an instantaneous simplebending deformation in the gradient coil 21, resulting in the vibration of the gradient coil 21. Here, as the currents I have no prominent component, the characteristic vibration mode shown in Fig. 8(B) which is the closest to the mode of induced forces F will arises and, as shown in Fig. 8(A), a characteristic frequency of about 500 Hz corresponding to this mode of vibration becomes dominant.

Such vibration of the gradient coil 21 causes the vibration of the inner shell 7 through the air between the gradient coil 21 and the inner shell 7. Here, the vibration frequency of the inner shell 7is identical to that of the gradient coil 21 as shown in Fig. 9(A), but the vibration mode for the inner shell 7 is different from that of the gradient coil 21 as shown in Fig. 9(B), because the vibration is mediated by the air and also because the vibration of the inner shell 7 is associated with that of the outer shell 2 which supports it.

Such vibration of the inner shell 7 in turn gives rise to the acoustic noise inside the measurement space. As shown in Fig. 10(A), a major contribution to this acoustic noise comes from the characteristic frequency of the vibration of the inner shell 7, which is equal to the characteristic frequency of the vibration of the gradient coil 21 as mentioned above. It is further shown in Fig. 10(B) that the acoustic noise is not uniform along a central axis through the measurement space.

On the basis of this analysis, the insertion of the viscoelastic layer 9 in the inner shell 7 which lies between the gradient coil 21 and the measurement space, as in the first embodiment described above, will be effective in reducing the generation of the acoustic noisesbecause this viscoelastic layer 9 functions to interrupt the route of the propagation of the acoustic noises

In order to verify this, the following first experiment had been conducted by the present inventor.

Fig. 11 shows the actual configuration of a nuclear magnetic resonance imaging apparatus used in this first experiment. In this nuclear magnetic resonance imaging apparatus, the transmitter and receiver coil is wound around

the inner shell 7. An acceleration pickup is attached on this transmitter and receiver coil at a middle in the direction of the central axis of the measurement space, as shown by a point K in Fig. 12. The frequency characteristics of the acoustic noises are measured with this acceleration pickup for both the nuclear magnetic resonance imaging apparatus of Fig. 11 (with the viscoelastic layer 9) and a conventional nuclear magnetic resonance imaging apparatus of similar type (without the viscoelastic layer 9).

The result of this experiment is shown in Fig. 13, where the frequency characteristic obtained by the nuclear magnetic resonance imaging apparatus of Fig. 11 (with the viscoelastic layer 9) which is represented by a solid curve is contrasted against that obtained by the conventional nuclear magnetic resonance imaging apparatus of similar type (without the viscoelastic layer 9) which is represented by a dashed curve. Fig. 13 clearly indicates that the vibration of the transmitter and receiver coil in the nuclear magnetic resonance imaging apparatus of Fig. 11 is substantially reduced over entire range of frequencies, and particularly around the characteristic frequency of 500 Hz, compared with that in the conventional nuclear magnetic resonance apparatus.

Considering the direct relationship between the vibration of the transmitter and receiver coil and the acoustic noise, it can be concluded therefore that with the first embodiment of the present invention, the significant reduction of the acoustic noise inside the measurement space can be achieved.

The mechanism for this reduction of the acoustic noise by the inserted viscoelastic layer 9 has been analyzed by the present inventor as follows.

As already mentioned, in a configuration such as that of Fig. 11 in which the viscoelastic layer 9 is inserted in a middle of the inner shell 7, the electromagnetic forces will be exerted on each coil winding as the pulsed currents are fed in the presence of the static magnetic field. The resulting vibration of the gradient coil 21 will then be propagated through the air as well as through members supporting the gradient coil 21 to the inner shell 7, causing the bending vibration of the inner shell 7 which is a direct cause of the acoustic noise in the measurement space. In such a situation, it has been observed that the viscoelastic layer 9 is primarily subjected to shearing deformation.

Fig. 14 depicts a simple shearing deformation on the viscoelastic layer 9 which is located between a first and second resin members 10 and 11 made of resin with relatively large Young's modulus such as epoxy resin. In Fig. 14, τ represents a shearing stress exerted on the viscoelastic layer 9.

Now, suppose the shearing stress τ causes the shear strain γ in the viscoelastic layer 9, and let the shearing stress τ and the shear strain γ be harmonic in time, then the shearing stress τ and the shear strain γ can be expressed in terms of complex shearing stress $\tilde{\tau}$ and the complex shear strain $\tilde{\tau}$ as:

$$\tau = \mathrm{Re}\ [\tilde{\tau} \cdot e^{-j\omega t}] \qquad (1)$$

$$\gamma = \mathrm{Re}\ [\tilde{\gamma} \cdot e^{-j\omega t}] \qquad (2)$$

where Re means a real part, j is an imaginary unit, ω is an angular frequency, and t is a time. Also, in general, the shear modulus G which characterizes elastic bodies is also expressed in a complex form as:

$$G = G_0\ (1 + j\beta) \qquad (3)$$

where the G_0 is a real shear modulus, and β is a loss factor. In addition, the relationship:

$$\tilde{\tau} = G \cdot \tilde{\gamma} \qquad (4)$$

holds.

Meanwhile the energy dissipation D dissipated by a unit volume of the viscoelastic layer 9 in one period of the vibration can be expressed as:

$$D = \oint Im[\tilde{\tau} \cdot e^{-j\omega t}]\dot{\gamma}\ dt \qquad (5)$$

$$= \oint G_B \beta |\gamma| \sin(\omega t + \phi) \cdot |\gamma| \sin(\omega t + \phi)\ dt$$
$$= \pi\omega G_B \beta |\gamma|^2 \qquad (6)$$

where Im means an imaginary part, and ϕ is an initial phase of the shear strain γ. The equation (6) shows that the energy dissipation D is proportional to the loss factor β and the square of the shear strain γ.

Moreover, for the situation of Fig. 14, the shear strain γ can be expressed in terms of displacement u of the resin members 10 and 11 as:

$$\gamma = \partial u / \partial y \qquad (7)$$

where y is a coordinate along a direction of the thickness of the viscoelastic layer 9. When the displacement u is small enough to be expressed as δu, the relation:

$$\gamma \simeq \delta u / \delta y \qquad (8)$$

holds.

Accordingly, it can be deduced from the equations (6), (7), and (8) that the energy dissipation D can be made large when the shear strain γ of the viscoelastic layer 9 is made large by making the thickness of the viscoelastic layer 9 (δy in Eq.(8)) as thin as possible.

As a more realistic model, a plate with sandwich structure comprising a constraining layer, viscoelastic layer and a structure member shown in Fig. 15 will now be considered. Such a model has been discussed by Yan and Dowell in Journal of Applied Mechanics, Dec. 1972, pp.1041-1046, in which they gives the equation of motion for vibration of such a model as:

$$\tilde{\beta}\nabla^4 s + \rho(\tilde{\alpha}/G_B)\nabla^2\ddot{s} + \rho\ddot{s} = 0 \qquad (9)$$

where s is a transverse displacement function of plate, ρ is a density, and:

$$\tilde{\beta} = (D_1 I_{1B} + D_3 I_{3B}) - \frac{(D_1 A_{1B} + D_3 A_{3B})^2}{D_1 h_1 + D_3 h_3} \qquad (10)$$

$$\tilde{\alpha} = \frac{D_1 D_3}{h_1 + h_2 + h_3} \frac{h_2 (h_3 A_{1B} - h_1 A_{3B})}{D_1 h_1 + D_3 h_3} \qquad (11)$$

$$D_1 = \frac{E_1}{1 - \nu_1^2},\ D_3 = \frac{E_3}{1 - \nu_3^2},\tag{12}$$

$$D_{10} = \frac{Z_1^2}{2},\ A_{30} = \frac{Z_3^2 - Z_2^2}{2}\tag{13}$$

$$I_{10} = \frac{Z_1^3}{3},\ I_{30} = \frac{Z_3^3 - Z_2^3}{3}\tag{14}$$

where E_1 and E_3 are Young's modulus for the structure member and the constraining layer, respectively, ν_1 and ν_3 are Poisson ratio for the structure member and the constraining layer, respectively, h_1, h_2 and h_3 are thickness of the structure member, the viscoelastic layer, and the constraining layer, respectively, and Z_1, Z_2 and Z_3 are Z-coordinate of the top of the structure member, the viscoelastic layer, and the constraining layer, respectively, with the bottom of the structure member having a Z-coordinate equal to 0. Also,:

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\tag{15}$$

i.e., a harmonic operator, and a dot over a letter represents a time derivative.

Now, assuming the harmonic time dependence of the the transverse displacement function of plate s, introducing a complex transverse displacement function of plate S as:

$$s = \mathrm{Re}\,[S \cdot e^{-jwt}]\tag{16}$$

where Re means a real part, j is an imaginary unit, ω is an angular frequency, and t is a time, and using the complex shear modulus given by the Eq.(3), the Eq.(9) becomes:

$$\tilde{\beta}\nabla^4 S + j\rho\omega^2 \frac{\tilde{\alpha}}{G_B} \frac{\beta}{1+\beta^2} \nabla^2 S - \rho\omega^2 S = 0 \quad \text{------} \ (17)$$

by regarding the conservation of the viscoelastic layer against shearing as negligible compared with the conservation of the structure member and the constraining layer against bending.

Then, from the Eq.(17), the energy dissipation D in one period of vibration can be obtained as:

$$D = \pi\rho\omega^2 \frac{-\tilde{\alpha}}{G_B} \frac{\beta}{1+\beta^2} \iint \{|S|(\nabla^2|S|)\}\ dxdy \quad \text{------} \ (18)$$

and the maximum of the potential energy E_{pmax} can be obtained as:

$$E_{pmax} = \tilde{\beta} \iint \{|S|(\nabla^4|S|)\}\ dxdy \quad \text{------} \ (19)$$

With these Eqs.(18) and (19), one can define a total loss factor η of the plate with sandwich structure as:

$$\eta = \frac{D}{2\pi E_{pmax}} \cdot \frac{\rho}{G_{\emptyset}} \frac{\beta}{1+\beta^2} \cdot \xi \cdot C_m \qquad (20)$$

where C_m is a part depending on the vibration frequency and the vibration mode of the plate, which is unimportant in what follows, and:

$$\xi = \frac{-\tilde{\alpha}}{2\tilde{\beta}} \qquad (21)$$

which is a dimensionless parameter. Now, using $r_1 = h_1/(h_1+h_2+h_3)$ and $r_2 = h_2/(h_1+h_2+h_3)$ and assuming that h_2 is sufficiently thinner than $h_1+h_2+h_3$ such that $0.25 \gg r_2$, the dimensionless parameter ξ can be expressed as:

$$\xi = \frac{3r_2 (r_1 - r_1^2)}{[R_D + (1/R_D)-2]r_1^4+4(1-R_D)r_1^3-6(1-R_D)r_1^2+4(1-R_D)r_1+R_D} \qquad (22)$$

where :

$$R_D = \frac{E_3 (1 - \nu_1^2)}{E_1 (1 - \nu_3^2)} \qquad (23)$$

which is a ratio of stiffness of the constraining layer and the structure member.

Now, the Eq.(20) gives the condition for obtaining larger total loss factor η as having larger loss factor β of the viscoelastic layer, having smaller shear modulus $G_{\emptyset}$, and having larger value for the dimensional parameter ξ. But, as can be seen from the Eq.(22), the dimensional parameter ξ is determined by R_D and r_1. The relationships of the dimensionless parameter ξ with respect to R_D and r_1 are shown in Fig. 16, which indicates that when $R_D = 1$ in which the stiffness of the structure member and the constraining layer is the same the dimensional parameter ξ is largest at $r_1 = 0.5$, i.e., when the viscoelastic layer is at the middle of the sandwich structure. In such a case, the total loss factor η also becomes large. Furthermore, for r_1 different from 0.5 in which there is a large difference between the flexural rigidity of the structure member and that of the constraining layer, both the dimensional parameter ξ as well as the total loss factor η become small. Similar results are obtained for R_D different from 1.0 as well. Thus, in order to have a large total loss factor η and a good damping characteristic together, the flexural rigidities of the structure member and the constraining layer are preferably as close to each other as possible. Also, it can be seen from Fig. 16 that, the dimensionless parameter ξ not less than 0.1 is desirable.

Summarizing the above analysis, using for the viscoelastic layer 9 a material with large loss factor β, having small Young's modulus and large Poisson ratio $\nu_{\emptyset}$ for which the shear modulus $G_{\emptyset} = E_{\emptyset} / 2(1 + \nu_{\emptyset})$ becomes small, and making the flexural rigidities of the resin members sandwiching the viscoelastic layer 9 to be as close to each other as possible, large total loss factor η can be obtained with satisfactory damping characteristic.

On the other hand, the thickness of the viscoelastic layer 9 is preferably thinner for the sake of larger shear strain, whereas it is preferably thicker for the sake of increasing the volume from which the energy can dissipate. In a practical nuclear magnetic resonance imaging apparatus, an appropriate value for the thickness of the viscoelastic layer is therefore within a range between 0.01mm and 3mm.

Referring now to Figs. 17 and 18, there is shown a second embodiment of a nuclear magnetic resonance imaging apparatus according to the present invention.

In this second embodiment, the gradient coil 21 is formed with a coil core 23 made of G-FRP (Glass-Fiber reinforced plastics) around which coils 27 and 29 are wound, an epoxy resin 24 which molds the coils 27 and 29, the viscoelastic layer 9 over the epoxy resin 24, and the outer layer 13 made also of G-FRP over the viscoelastic layer 9. Other feature of this second embodiment is substantially the same as the first embodiment.

The reason for providing the outer layer 13 made of G-FRP will now be explained.

First, it is to be noted that the Young's modulus for the epoxy resin is 250 kgf/mm^2, whereas that of the G-FRP is 1300 to 3200 kgf/mm^2, so that the G-FRP has a larger stiffness.

As mentioned above, in order to have a large total loss factor η, it is necessary to make the flexural rigidities of the resin members sandwiching the viscoelastic layer 9 to be as close to each other as possible.

However, in such a configuration, surrounding the viscoelastic layer 9 with the epoxy resin makes the flexural rigidity decreasing towards an outer edge, so that it becomes difficult to obtain a satisfactory total loss factor η.

On the other hand, althogh by using the same epoxy resin for inner side as well as outer side can make the flexural rigidities of the sandwiching resin member nearly equal, this also makes the gradient coil 21 thicker so that either the main magnet bore need to be enlarged or else the measurement space need to be narrowed, neither of which is desirable from a point of view of designing.

Thus, in the second embodiment, G-FRP which has a much larger stiffness are provided around the coil core 23 with relatively thinner thickness, so as to make the flexural rigidities of the resin members sandwiching the viscoelastic layer 9 to be as close to each other as possible.

In order to verify the effect of this second embodiment, the following second experiment had been conducted by the present inventor.

In this second experiment, a nuclear magnetic resonance imaging apparatus used is basically the same as that used in the first experiment shown in Fig. 11, except that the characteristic feature of the second embodiment shown in Figs. 17 and 18 is incorporated.

As shown in Fig. 19, in this second experiment, two acceleration pickups are separately attached to the gradient coil 21 at an edge of the measurement space shown by a point L and at a middle in the direction of the central axis of the measurement space shown by a point M.

Furthermore, as shown in Fig. 20, the microphones are placed at points N, P, Q, R, and S on the central axis of the measurement space as well as at a point T near a wall surrounding the measurement space, off the central axis at the middle in the direction of the central axis, so as to investigate the relationship between the vibration and the acoustic noise.

The measured acceleration at the points L and M as functions of time are shown in Figs. 21 and 22, espectively, in which the results obtained by the nuclear magnetic resonance imaging apparatus according to the second embodiment (with the viscoelastic layer 9 surrounded by the G-FRP outer shell) which are represented by solid curves are contrasted against those obtained by the conventional nuclear magnetic resonance imaging apparatus of similar type (without the viscoelastic layer 9 and the G-FRP outer shell) which are represented by dashed curves. It is clearly shown in Figs, 21 and 22 that the substantial reduction of the vibration is possible in the nuclear magnetic resonance imaging apparatus of the second embodiment, at the both points L and M, compared with the conventional nuclear magnetic resonance imaging apparatus.

Also, the measured acoustic noise levels at the points N, P, Q, R, S, and T are shown in Fig. 23, in which the results obtained by the nuclear magnetic resonance imaging apparatus according to the second embodiment (with the viscoelastic layer 9 surrounded by the G-FRP outer shell) which are represented by solid dots are contrasted against those obtained by the conventional nuclear magnetic resonance imaging apparatus of similar type (without the viscoelastic layer 9 and the G-FRP outer shell) which are represented by blank dots. It is clearly shown in Fig. 23 that the substantial reduction of the acoustic noise is also possible in the nuclear magnetic resonance imaging apparatus of the second embodiment compared with the conventional nuclear magnetic resonance imaging apparatus, by an average of approximately 3.25 dB, although the results slightly varies at different location.

Thus, the effectiveness of sandwich structure around the viscoelastic layer 9 in reducing the vibration of the gradient coil 21 as well as the acoustic noise in the measurement space had been vindicated once again, and the additional feature of G-FRP outer shell in the second embodiment had been shown to be effective in further reduction of the vibration and the acoustic noise.

Referring now to Figs. 24 and 25, there is shown a third embodiment of a nuclear magnetic resonance imaging apparatus according to the present invention.

In this third embodiment, the viscoelastic layer 9 is formed inside the epoxy resin 24 molding the coils 27 and 29. Such a formation of the viscoelastic layer 9 can be accomplished by the manner similar to that suggested in the explanation of the first embodiment for forming the viscoelastic layer 9 inside the inner shell 7.

In this configuration of the third embodiment, the viscoelastic layer 9 also functions to dissipate the vibration energy and to reduce the vibration of the gradient coil 21, so that the similar result concerning the reduction of the acoustic noise can be obtained. Moreover, since the Eqs.(6), (7), (8), (20), and (22) given above for the first embodiment also hold for this third embodiment, the same criteria that the vibration of the epoxy resin 24 can be reduced by making the energy dissipation D larger using the thin viscoelastic layer 9 of smaller Young's modulus also applies for this third embodiment.

Similarly, the other embodiments are conceivable in which the location of the viscoelastic layer 9 is changed without

alterring the effect of the viscoelastic layer 9.

Thus, Fig. 26 shows a fourth embodiment of a nuclear magnetic resonance imaging apparatus according to the present invention, in which the viscoelastic layer 9 is formed inside the coil core 23 of the gradient coil 21.

Likewise, Fig. 27 shows a fifth embodiment of a nuclear magnetic resonance imaging apparatus according to the present invention, in which the viscoelastic layer 9 is formed between the coil core 23 of the gradient coil 21 and the resin 24 molding the coils 27 and 29.

Also, Fig. 28 shows a sixth embodiment of a nuclear magnetic resonance imaging apparatus according to the present invention, in which the viscoelastic layer 9 is formed inside the outer shell 2 which supports the gradient coil 21 against the main magnet 1.

Further variations can be obtained as the combination of the above embodiments, such as one in which the outer layer 13 made of G-FRP of the second embodiment is incorporated to any one of the third, fourth fifth, or sixth embodiment above.

It is also to be noted that although in all of the embodiments described above, the viscoelastic layer 9 has been described as a single layer, this may be modified to multi-layer configurations.

Furthermore, although in all of the embodiments described above, the viscoelastic layer 9 has been formed in cylindrical shape along the cylindrical shells, partial or fragmental use of the feature of the present invention may also be effective.

In addition, although in all of the embodiments described above, the sandwich structure around the viscoelastic layer 9 has been provided by other components of the nuclear magnetic resonance imaging apparatus which are necessary regardless of the presence of the viscoelastic layer 9, this sandwich structure may be formed by providing additional resin members exclusively for this purpose.

It is also obvious that although the embodiments has been described for a particular model of a nuclear magnetic resonance imaging apparatus, the features of the present invention can be incorporated just as effectively and beneficially in other models of nuclear magnetic resonance imaging apparatuses.

Besides these, many modifications and variations of these embodiments may be made without departing from the novel and advantageous features of the present invention. Accordingly, all such modifications and variations are intended to be included within the scope of the appended claims.

Reference signs in the claims are intended for better understanding and shall not limit the scope.

Claims

1. A nuclear magnetic resonance imaging apparatus, comprising:

   a main magnet (1) for generating a static magnetic field in a measurement space in which a body to be examined is to be placed;

   gradient coil means (21) for producing gradient magnetic fields over the static magnetic field;

   means for detecting signals from the body in the static and gradient magnetic fields due to a nuclear magnetic resonance phenomenon; and

   means for processing the detected signals so as to obtain tomographic images of the body at arbitrary cross sections;

   characterised by:

   a vibration reducing sandwich structure which is located between the body and the main magnet (1) and formed by a viscoelastic layer (9) sandwiched between first and second sandwiching members, for reducing a vibration of the gradient coil means (21) by a shearing deformation of the viscoelastic layer (9) between the first and second sandwiching members.

2. The apparatus of claim 1, wherein the sandwich structure is arranged in a vicinity of the gradient coil means (21) while making one of a direct and an indirect contact with the gradient coil means (21).

3. The apparatus of claim 1, wherein the detecting means comprises transmitter and receiver coil means, and wherein the sandwich structure is arranged in a vicinity of the detecting means.

4. The apparatus of claim 1, wherein at least one of the first and second members of the sandwich structure is located

within the measurement space, and comprises a hollow member which serves as a coil core for the detecting means.

5. The apparatus of claim 1, wherein at least one of the first and second members of the sandwich structure comprises a a coil core for the gradient coil means(21).

6. The apparatus of claim 1, wherein the gradient coil means(21) comprises coils wound around a coil core and a resin molding the coils which also serves as at least one of the first and second sandwiching members of the sandwich structure.

7. The apparatus of claim 1, wherein the gradient coil means(21) comprises coils wound around a coil core, a first resin molding the coils, and a second resin having a larger stiffness than the first resin, the second resin surrounding the first resin, the second resin being also serving as at least one of the first and second sandwiching members of the sandwich structure.

8. The apparatus of claim 1, wherein the gradient coil means(21) is supported to the main magnet(1) by a hollow member which also serves as at least one of the first and second sandwiching members of the sandwich structure.

9. The apparatus of claim 1, wherein the Young's modulus of the viscoelastic layer(9) is smaller than that of the first sandwiching member as well as that of the second sandwiching member.

10. The apparatus of claim 1, wherein the loss factor of the viscoelastic layer(9) is larger than that of the first sandwiching member as well as that of the second sandwiching member.

11. The apparatus of claim 1, wherein the shear modulus of the viscoelastic layer(9) is smaller than that of the first sandwiching member as well as that of the second sandwiching member.

12. The apparatus of claim 1, wherein the flexural rigidities of the first and second sandwiching members are substantially equal to each other.

13. The apparatus of claim 1, wherein the thickness of the viscoelastic layer(9) is thinner than that of the first and second sandwiching members together.

14. The apparatus of claim 1, wherein the thickness of the viscoelastic layer(9) is within a range between 0.01mm and 3.0mm.

15. The apparatus of claim 1, wherein the viscoelastic layer(9) is made of polymer compound.

16. The apparatus of claim 1, wherein the viscoelastic layer(9) is formed by pouring in a liquid viscoelastic material into a space between the first and second sandwiching members.

17. The apparatus of claim 1, wherein the sandwich structure is such that a dimensional parameter given by:

$$\xi = \frac{3r_2\,(r_1 - r_1^{\,2})}{[R_D + (1/R_D)-2]r_1^{\,4}+4(1-R_D)r_1^{\,3}-6(1-R_D)r_1^{\,2}+4(1-R_D)r_1+R_D}$$

where $r_1 = h_1/(h_1+h_2+h_3)$, $r_2 = h_2/(h_1+h_2+h_3)$,h_1 is a thickness of the first sandwiching member, h_2 is a thickness of the viscoelastic layer(9), h_3 is a thickness of the second sandwiching member, and R_D is a ratio of stiffness of the first and second sandwiching members, satisfies an inequality:

$$\xi \geq 0.1$$

18. The apparatus of claim 1, wherein one of the first and second sandwiching members is made of a material with larger stiffness than another one, which is also thinner in thickness than another one.

19. The apparatus of claim 18, wherein one of the first and second sandwiching members with larger stiffness is made of G-FRP (Glass-Fiber reinforced plastics) while another one is made of a resin.

20. The apparatus of claim 18, wherein one of the first and second sandwiching members with larger stiffness is located further away from the measurement space than another one.

21. A nuclear magnetic resonance imaging apparatus according to claim 1, characterised in that said vibration reducing sandwich structure comprises a hollow member (7) defining a hollow region inside its wall thickness, which is filled with said viscoelastic layer (9).

22. A nuclear magnetic resonance imaging apparatus, according to claim 1, characterised in that the gradient coil means (21) comprises a coil core (23) and coils (27, 29) wound around the coil core (23), said coil core containing a viscoelastic layer (9) inside the coil core so as to form therewith said vibration reducing sandwich structure.

23. The apparatus of claim 1, wherein the gradient coil means (21) comprises a coil core (23), coils (27, 29) wound around the coil core, a first resin (24) molding the coils, and a second resin (13) having a larger stiffness than the first resin, the second resin (13) surrounding the first resin (24), at least one of (a) a region inside the second resin (13) and (b) between the first resin (24) and second resin (13) containing said viscoelastic layer (9), so as, together with said second resin (13) and/or together with said first and second resins (24, 13), as the case may be, to form said sandwich structure.

24. The apparatus of claim 1, wherein the gradient coil means (21) comprises a coil core (23), coils (27,29) wound around the coil core, a resin (24) molding the coils (27, 29), at least one of (a) a region inside the resin (24) and (b) between the coil core (23) and resin (24) containing said viscoelastic layer (9), so as, together with said resin (24) and/or together with the coil core (23) and resin (24), as the case may be, to form said sandwich structure.

25. The apparatus of claim 21, wherein said hollow member is an outer shell (2) which surrounds and supports the gradient coil means (21) against the main magnet (1).

Patentansprüche

1. Kernmagnetresonanz-Bilderzeugungsvorrichtung mit:

einem Hauptmagneten (1) zur Erzeugung eines statischen Magnetfeldes in einem Meßraum, in welchem ein zu untersuchender Körper angeordnet werden kann;

einer Gradientenspulenvorrichtung (21) zur Erzeugung das statische Magnetfeld überlagernder Gradientenmagnetfelder;

einer Vorrichtung zum Nachweis von Signalen von dem Körper in dem statischen Magnetfeld und den Gradientenmagnetfeldern infolge des Effekts der kernmagnetischen Resonanz; und

einer Vorrichtung zur Verarbeitung der nachgewiesenen Signale, um so tomographische Bilder des Körpers in frei wählbaren Querschnitten zu erhalten;

gekennzeichnet durch:
eine Schwingungsverringerungs-Sandwichanordnung, welche zwischen dem Körper und dem Hauptmagneten (1) angeordnet ist, und durch eine sandwichartig zwischen einem ersten und zweiten Sandwichteil eingeschlossene viskoelastische Schicht (9) gebildet wird, um Vibrationen der Gradientenspulenvorrichtung (21) durch eine Scherverformung der viskoelastischen Schicht (9) zwischen dem ersten und zweiten Sandwichteil zu verringern.

2. Vorrichtung nach Anspruch 1, bei welcher die Sandwichanordnung in der Nähe der Gradientenspulenvorrichtung (21) angeordnet ist, und entweder in direktem oder in indirektem Kontakt mit der Gradientenspulenvorrichtung (21) steht.

3. Vorrichtung nach Anspruch 1, bei welcher die Nachweisvorrichtung eine Sende- und Empfangsspulenvorrichtung aufweist, und wobei die Sandwichanordnung in der Nähe der Nachweisvorrichtung angeordnet ist.

4. Vorrichtung nach Anspruch 1, bei welcher zumindest entweder das erste oder das zweite Teil der Sandwichanordnung innerhalb des Meßraumes liegt, und ein hohles Teil aufweist, welches als Spulenkern für die Nachweisvorrichtung dient.

5. Vorrichtung nach Anspruch 1, bei welcher zumindest entweder das erste oder das zweite Teil der Sandwichanordnung einen Spulenkern für die Gradientenspulenvorrichtung (21) aufweist.

6. Vorrichtung nach Anspruch 1, bei welcher die Gradientenspulenvorrichtung (21) Spulen aufweist, die um einen Spulenkern herumgewickelt sind, sowie ein Kunstharz, welches die Spulen einformt, und auch als zumindest entweder das eine oder das andere Sandwichteil der Sandwichanordnung dient.

7. Vorrichtung nach Anspruch 1, bei welcher die Gradientenspulenvorrichtung (21) Spulen aufweist, die um einen Spulenkern herumgewickelt sind, ein erstes Kunstharz, welches die Spulen einformt, sowie ein zweites Kunstharz, welches eine höhere Steifigkeit aufweist als das erste Kunstharz, wobei das zweite Kunstharz das erste Kunstharz umgibt, und das zweite Kunstharz auch als zumindest entweder das erste oder das zweite Sandwichteil der Sandwichanordnung dient.

8. Vorrichtung nach Anspruch 1, bei welcher die Gradientenspulenvorrichtung (21) an dem Hauptmagneten (1) durch ein hohles Teil gehaltert wird, welches auch als zumindest entweder das erste oder das zweite Sandwichteil der Sandwichanordnung dient.

9. Vorrichtung nach Anspruch 1, bei welcher der Elastizitätsmodul der viskoelastischen Schicht (9) kleiner ist als jener des ersten Sandwichteils und jener des zweiten Sandwichteils.

10. Vorrichtung nach Anspruch 1, bei welcher der Verlustfaktor der viskoelastischen Schicht (9) größer ist als jener des ersten Sandwichteils und größer als jener des zweiten Sandwichteils.

11. Vorrichtung nach Anspruch 1, bei welcher der Schermodul der viskoelastischen Schicht (9) kleiner ist als jener des ersten Sandwichteils und kleiner als jener des zweiten Sandwichteils.

12. Vorrichtung nach Anspruch 1, bei welcher die Biegesteifigkeiten des ersten und zweiten Sandwichteils im wesentlichen gleich sind.

13. Vorrichtung nach Anspruch 1, bei welcher die Dicke der viskoelastischen Schicht (9) geringer ist als die Gesamtdicke des ersten und zweiten Sandwichteils.

14. Vorrichtung nach Anspruch 1, bei welcher die Dicke der viskoelastischen Schicht (9) innerhalb eines Bereiches von 0,01 mm bis 3,0 mm liegt.

15. Vorrichtung nach Anspruch 1, bei welcher die viskoelastische Schicht (9) aus einer Polymerverbindung besteht.

16. Vorrichtung nach Anspruch 1, bei welcher die viskoelastische Schicht (9) dadurch ausgebildet wird, daß ein flüssiges, viskoelastisches Material in einen Raum zwischen dem ersten und zweiten Sandwichteil eingegossen wird.

17. Vorrichtung nach Anspruch 1, bei welcher die Sandwichanordnung so ausgebildet ist, daß ein dimensionsloser Parameter, der gegeben ist durch:

$$\xi = \frac{3r_2\,(r_1 - r_1^2)}{[R_D + (1/R_D)-2]r_1^4+4(1-R_D)r_1^3-6(1-R_D)r_1^2+4(1-R_D)r_1+R_D}$$

wobei $r_1 = h_1 / (h_1 + h_2 + h_3)$ ist, $r_2 = h_2 / (h_1 + h_2 + h_3)$, h_1 die Dicke des ersten Sandwichteils ist, h_2 die Dicke der viskoelastischen Schicht (9) ist, h_3 die Dicke des zweiten Sandwichteils ist, und R_D das Verhältnis der Steifigkeiten des ersten und zweiten Sandwichteils ist, folgende Ungleichung erfüllt:

$$\xi \geq 0{,}1$$

18. Vorrichtung nach Anspruch 1, bei welcher entweder das erste oder das zweite Sandwichteil aus einem Material mit höherer Steifigkeit besteht als das andere Teil, und ebenfalls eine geringere Dicke aufweist als das andere Teil.

19. Vorrichtung nach Anspruch 18, bei welcher dasjenige von dem ersten und zweiten Sandwichteilen, welches eine höhere Steifigkeit aufweist, aus GFK (glasfaserverstärktem Kunststoff) besteht, wogegen das andere aus einem Kunstharz besteht.

20. Vorrichtung nach Anspruch 18, bei welchem dasjenige der ersten und zweiten Sandwichteile mit größerer Steifigkeit weiter entfernt von dem Meßraum angeordnet ist als das andere.

21. Kernmagnetresonanz-Bilderzeugungsvorrichtung nach Anspruch 1,
dadurch **gekennzeichnet** , daß die Schwingungsverringerungs-Sandwichanordnung ein hohles Teil (7) aufweist, welches innerhalb einer Wanddicke einen hohlen Bereich ausbildet, welcher mit der viskoelastischen Schicht (9) gefüllt ist.

22. Kernmagnetresonanz-Bilderzeugungsvorrichtung nach Anspruch 1,
dadurch **gekennzeichnet** , daß die Gradientenspulenvorrichtung (21) einen Spulenkern (23) und Spulen (27, 29) aufweist, die um den Spulenkern (23) herumgewickelt sind, wobei der Spulenkern in seinem Inneren eine viskoelastische Schicht (9) enthält, um so mit dieser zusammen die Schwingungsverringerungs-Sandwichanordnung auszubilden.

23. Vorrichtung nach Anspruch 1, bei welcher die Gradientenspulenvorrichtung (21) einen Spulenkern (23) aufweist, um den Spulenkern herumgewickelte Spulen (27, 29), ein erstes Kunstharz (24), welches die Spulen einformt, und ein zweites Kunstharz (13), welches eine höhere Steifigkeit aufweist als das erste Kunstharz, wobei das zweite Kunstharz (13) das erste Kunstharz (24) umgibt, und wobei zumindest entweder (a) ein Bereich innerhalb des zweiten Kunstharzes (13) oder (b) ein Bereich zwischen dem ersten Kunstharz (24) und dem zweiten Kunstharz (13) die viskoelastische Schicht (9) enthält, um so zusammen mit dem zweiten Kunstharz (13) und/oder zusammen mit dem ersten und zweiten Kunstharz (24, 13), je nach Fall, die Sandwichanordnung auszubilden.

24. Vorrichtung nach Anspruch 1, bei welcher die Gradientenspulenvorrichtung (21) einen Spulenkern (23) aufweist, um den Spulenkern herumgewickelte Spulen (27, 29), ein Kunstharz (24), welches die Spulen (27, 29) einformt, wobei zumindest entweder (a) ein Bereich innerhalb des Kunstharzes (24) oder (b) ein Bereich zwischen dem Spulenkern (23) und dem Kunstharz (24) die viskoelastische Schicht (9) enthält, um so zusammen mit dem Kunstharz (24) und/oder zusammen mit dem Spulenkern (23) und dem Kunstharz (24), je nach Fall, die Sandwichanordnung auszubilden.

25. Vorrichtung nach Anspruch 21, bei welcher das hohle Teil eine Außenschale (2) ist, welche die Gradientenspulenvorrichtung (21) umgibt und diese gegenüber dem Hauptmagneten (1) haltert.

Revendications

1. Appareil d'imagerie par résonance magnétique nucléaire, comprenant:

   un aimant principal (1) pour créer un champ magnétique statique dans un espace de mesure dans lequel doit être placé un corps à examiner;
   un moyen à bobine de gradient (21), pour produire des gradients de champ magnétique superposés au champ magnétique statique;
   un moyen pour détecter des signaux provenant du corps placé dans le champ magnétique statique et dans les gradients de champ magnétique, suite à un phénomène de résonance magnétique nucléaire; et
   un moyen pour traiter les signaux détectés, de manière à obtenir des images tomographiques du corps dans des sections transversales arbitraires;

   caractérisé par:
   une structure en sandwich de réduction des vibrations, disposée entre le corps et l'aimant principal (1) et formée par une couche viscoélastique (9) prise en sandwich entre un premier et un deuxième élément d'intercalation, pour réduire une vibration du moyen (21) à bobine de gradient par une déformation de cisaillement de la couche viscoélastique (9) située entre le premier et le deuxième élément d'intercalation.

2. Appareil selon la revendication 1, dans lequel la structure en sandwich est agencée au voisinage du moyen (21) à bobine de gradient, tout en étant en contact direct ou indirect avec le moyen (21) à bobine de gradient.

3. Appareil selon la revendication 1, dans lequel le moyen de détection comprend un moyen à bobine d'émission et de réception, et dans lequel la structure en sandwich est agencée au voisinage du moyen de détection.

4. Appareil selon la revendication 1, dans lequel au moins l'un parmi le premier et le deuxième élément de la structure en sandwich est disposé à l'intérieur de l'espace de mesure et comprend un élément creux qui sert de noyau de bobine pour le moyen de détection.

5. Appareil selon la revendication 1, dans lequel au moins l'un parmi le premier et le deuxième élément de la structure en sandwich comporte un noyau de bobine pour le moyen (21) à bobine de gradient.

6. Appareil selon la revendication 1, dans lequel le moyen (21) à bobine de gradient comprend des bobines enroulées autour d'un noyau de bobine, et une résine moulant les bobines, qui sert également comme au moins l'un parmi le premier et le deuxième élément d'intercalation de la structure en sandwich.

7. Appareil selon la revendication 1, dans lequel le moyen (21) à bobine de gradient comprend des bobines enroulées autour d'un noyau de bobine, une première résine moulant les bobines et une deuxième résine présentant une rigidité plus élevée que la première résine, la deuxième résine entourant la première résine, la deuxième résine servant également comme au moins l'un parmi le premier et le deuxième élément d'intercalation de la structure en sandwich.

8. Appareil selon la revendication 1, dans lequel le moyen (21) à bobine de gradient est soutenu sur l'aimant principal (1) par un élément creux qui sert également comme au moins l'un parmi le premier et le deuxième élément de la structure en sandwich.

9. Appareil selon la revendication 1, dans lequel le module de Young de la couche viscoélastique (9) est inférieur à celui du premier élément d'intercalation, ainsi qu'à celui du deuxième élément d'intercalation.

10. Appareil selon la revendication 1, dans lequel le facteur de perte de la couche viscoélastique (9) est supérieur à celui du premier élément d'intercalation, ainsi qu'à celui du deuxième élément d'intercalation.

11. Appareil selon la revendication 1, dans lequel le module de cisaillement de la couche viscoélastique (9) est inférieur à celui du premier élément d'intercalation ainsi qu'à celui du deuxième élément d'intercalation.

12. Appareil selon la revendication 1, dans lequel les rigidités en flexion du premier et du deuxième élément d'intercalation sont essentiellement identiques.

13. Appareil selon la revendication 1, dans lequel l'épaisseur de la couche viscoélastique (9) est plus faible que celle du premier et du deuxième élément d'intercalation pris ensemble.

14. Appareil selon la revendication 1, dans lequel l'épaisseur de la couche viscoélastique (9) se situe dans un intervalle de 0,01 mm à 3,0 mm.

15. Appareil selon la revendication 1, dans lequel la couche viscoélastique (9) est réalisée en un composé polymère.

16. Appareil selon la revendication 1, dans lequel la couche viscoélastique (9) est formée en versant un matériau viscoélastique liquide dans un espace situé entre le premier et le deuxième élément d'intercalation.

17. Appareil selon la revendication 1, dans lequel la structure en sandwich est telle qu'un paramètre dimensionnel donné par:

$$\xi = \frac{3r_2\,(r_1 - r_1^{\,2})}{[R_D + (1/R_D)-2]r_1^{\,4}+4(1-R_D)r_1^{\,3}-6(1-R_D)r_1^{\,2}+4(1-R_D)r_1+R_D}$$

où $r_1 = h_1/(h_1+h_2+h_3)$, $r_2 = h_2/(h_1+h_2+h_3)$, h_1 est une épaisseur du premier élément d'intercalation, h_2 est une épaisseur de la couche viscoélastique (9), h_3 est une épaisseur du deuxième élément d'intercalation et R_D est un rapport entre la rigidité du premier et celle du deuxième élément d'intercalation, vérifie une inégalité:

$$\xi \geq 0,1$$

18. Appareil selon la revendication 1, dans lequel l'un parmi le premier et le deuxième élément d'intercalation est réalisé en un matériau qui présente une rigidité plus grande que l'autre, et dont l'épaisseur est également plus faible que celle de l'autre.

19. Appareil selon la revendication 18, dans lequel l'un parmi le premier et le deuxième élément d'intercalation, qui présente une rigidité plus élevée, est réalisé en G-FRP ("Glass-Fiber reinforced plactics" - plastique renforcé de fibres de verre), l'autre étant réalisé en résine.

20. Appareil selon la revendication 18, dans lequel l'un parmi le premier et le deuxième élément d'intercalation, qui présente une rigidité plus élevée, est situé plus loin que l'autre de l'espace de mesure.

21. Appareil d'imagerie par résonance magnétique nucléaire selon la revendication 1, caractérisé en ce que ladite structure en sandwich de réduction des vibrations comprend un élément creux (7) définissant une région creuse à l'intérieur de son épaisseur de paroi, qui est rempli par ladite couche viscoélastique (9).

22. Appareil d'imagerie par résonance magnétique nucléaire selon la revendication 1, caractérisé en ce que le moyen (21) à bobine de gradient comprend un noyau de bobine (23) et des bobines (27, 29) enroulées autour du noyau de bobine (23), ledit noyau de bobine contenant une couche viscoélastique (9) à l'intérieur du noyau de bobine, de manière à former avec elle ladite structure en sandwich de réduction des vibrations.

23. Appareil selon la revendication 1, dans lequel le moyen (21) à bobine de gradient comprend un noyau de bobine (23), des bobines (27, 29) enroulées autour du noyau de bobine, une première résine (24) moulant les bobines et une deuxième résine (13) présentant une rigidité plus élevée que la première résine, la deuxième résine (13) entourant la première résine (24), au moins l'une parmi (a) une région située à l'intérieur de la deuxième résine (13) et (b) entre la première résine (24) et la deuxième résine (13), contenant ladite couche viscoélastique (9) de façon à former ladite structure en sandwich avec ladite deuxième résine (13) et/ou avec ladite première et ladite deuxième résine (24, 13), suivant le cas.

24. Appareil selon la revendication 1, dans lequel le moyen (21) à bobine de gradient comprend un noyau de bobine (23), des bobines (27, 29) enroulées autour du noyau de bobine, une résine (24) moulant les bobines (27, 29), au moins l'une parmi (a) une région située à l'intérieur de la résine (24) et (b) entre le noyau de bobine (23) et la résine (24), contenant ladite couche viscoélastique (9), de façon à former ladite structure en sandwich avec ladite résine (24) et/ou avec le noyau de bobine (23) et la résine (24), suivant le cas.

25. Appareil selon la revendication 21, dans lequel ledit élément creux est une enveloppe extérieure (2) qui entoure et soutient le moyen (21) à bobine de gradient contre l'aimant principal (1).

FIG.1
(PRIOR ART)

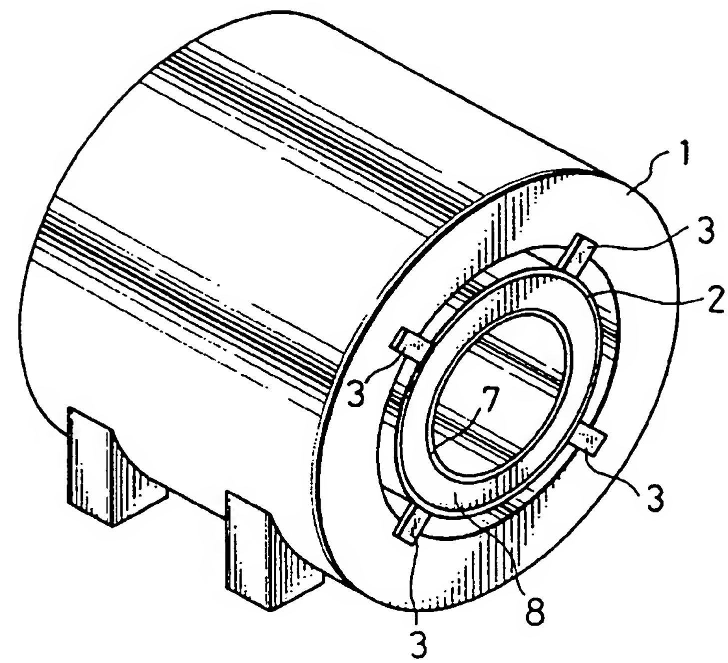


FIG.2
(PRIOR ART)

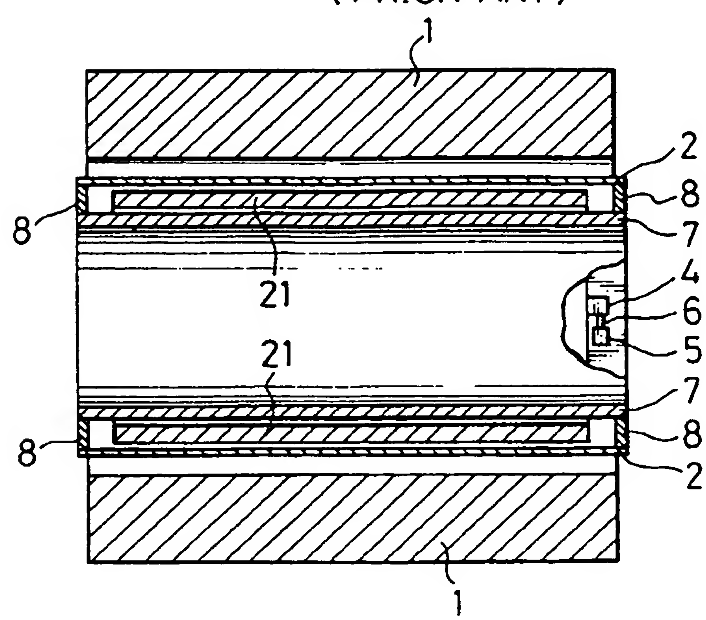


FIG. 3
(PRIOR ART)

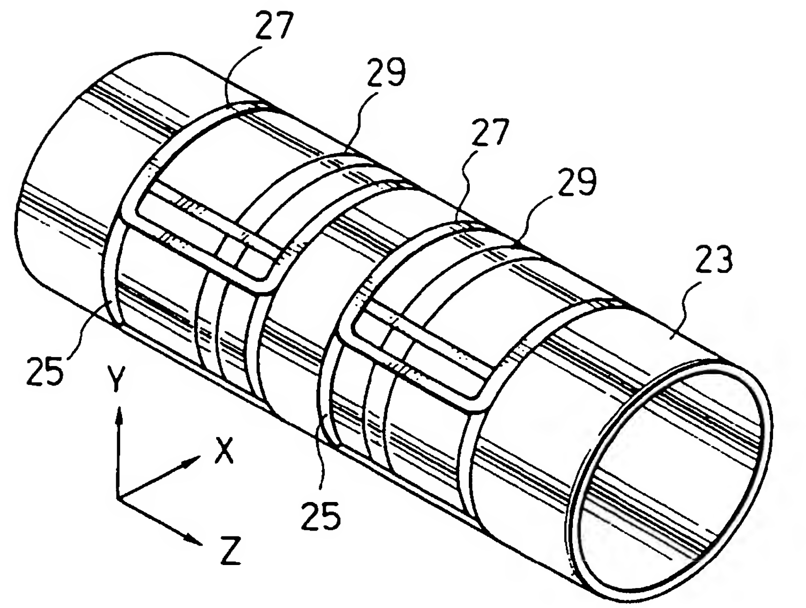


FIG. 4
(PRIOR ART)

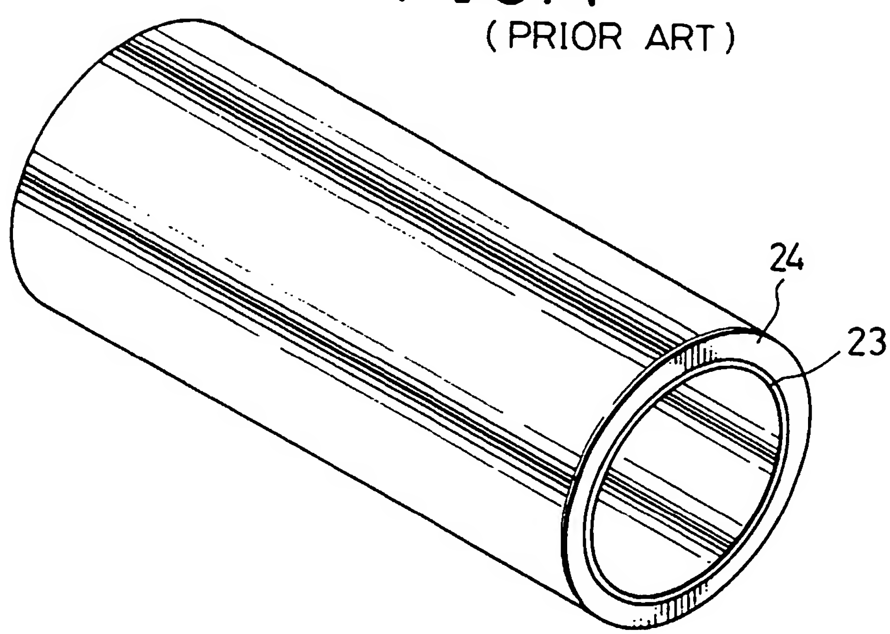


FIG.5

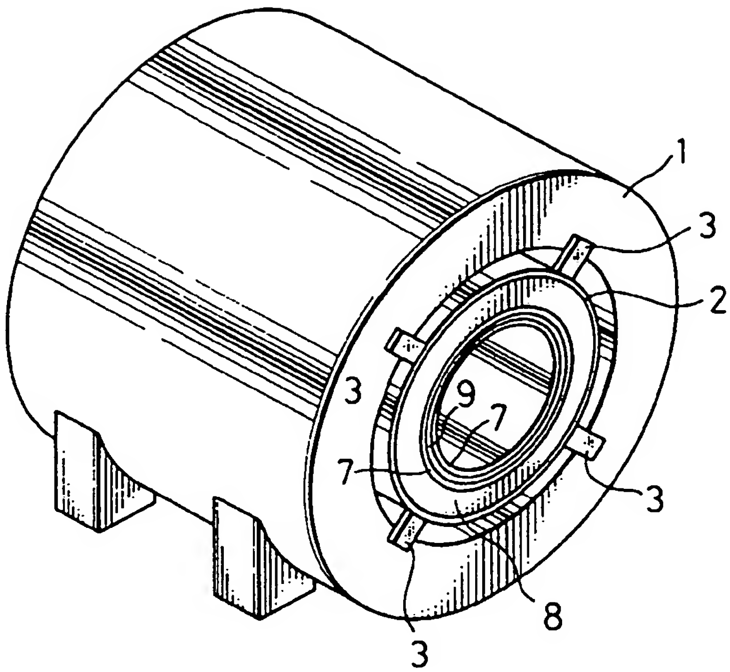


FIG.6

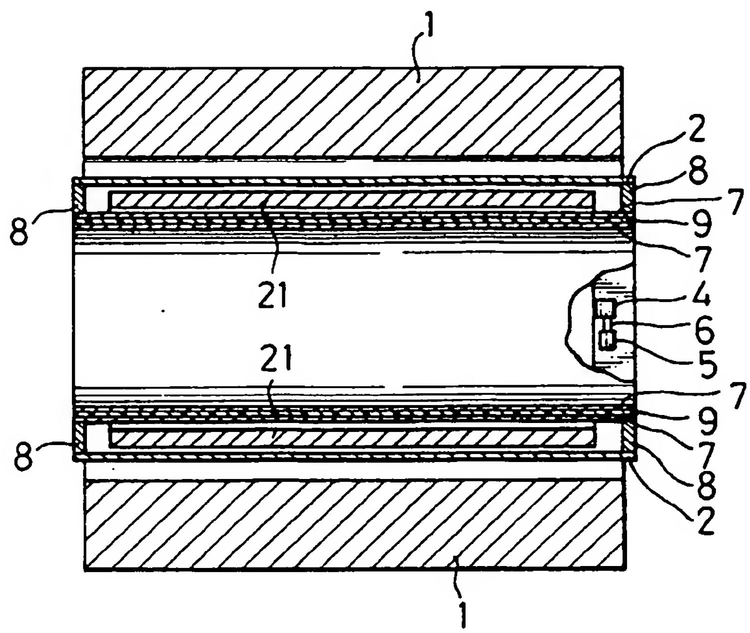


FIG.7(A)

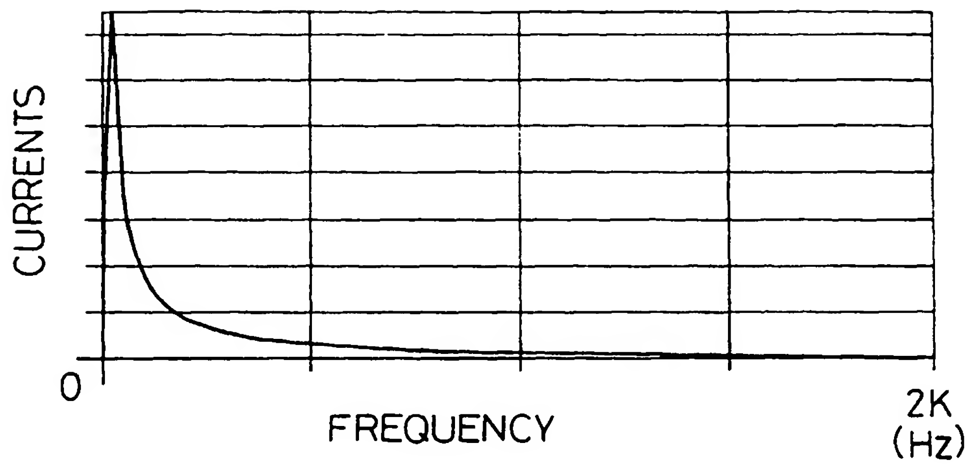


FIG.7(B)

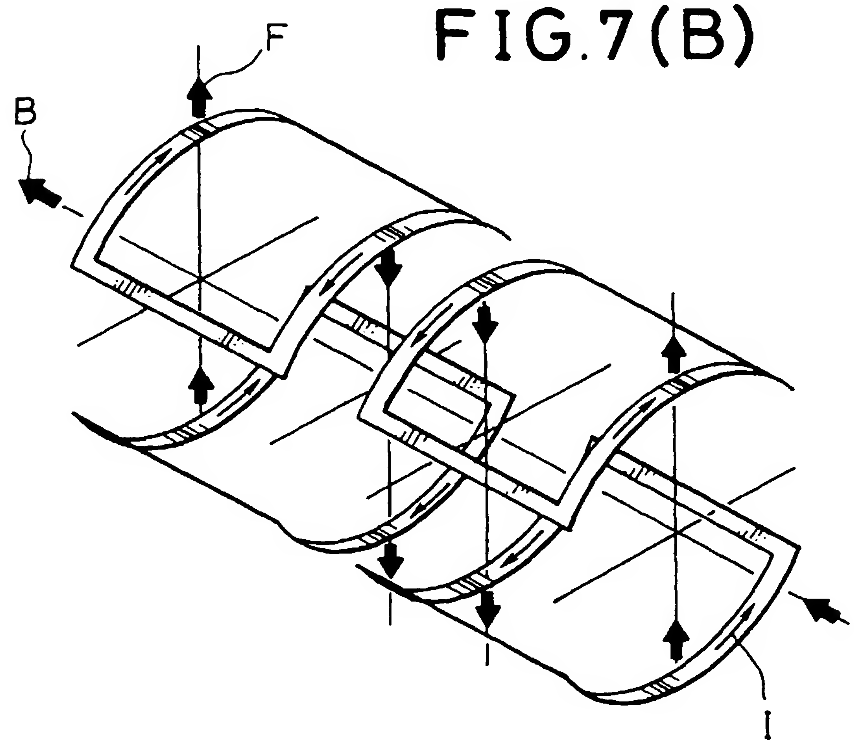


FIG. 8(A)

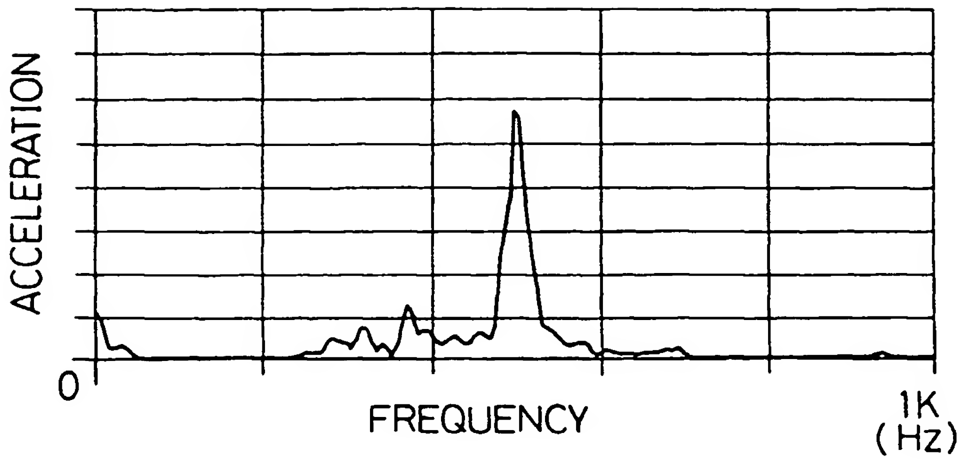


FIG. 8(B)

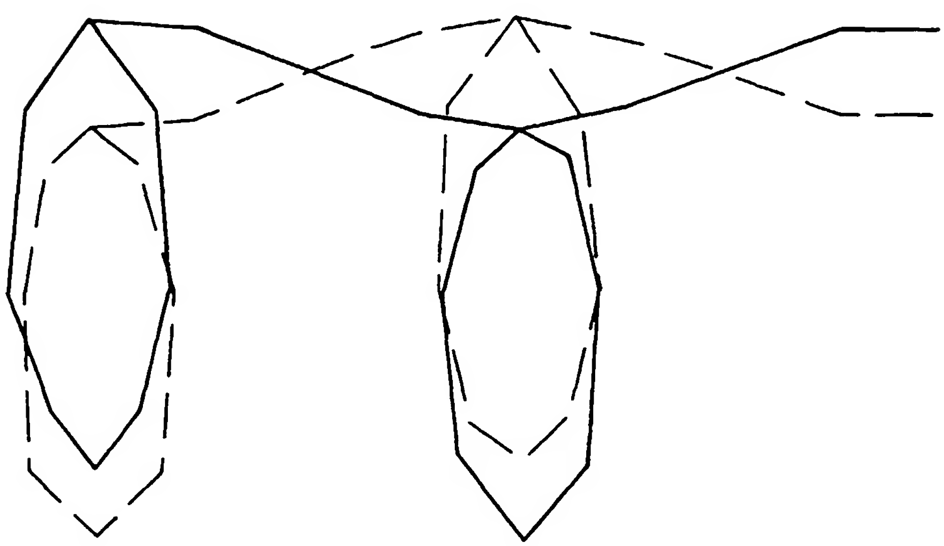


FIG.9(A)

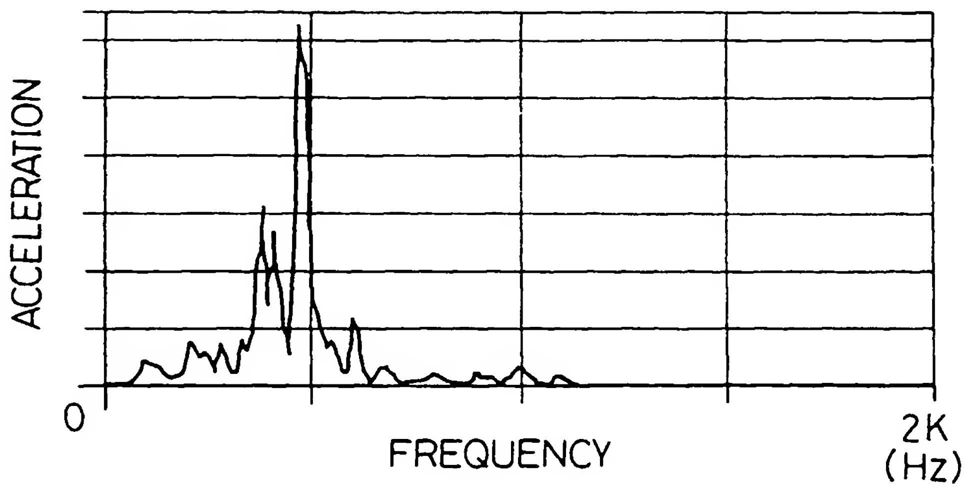


FIG.9(B)

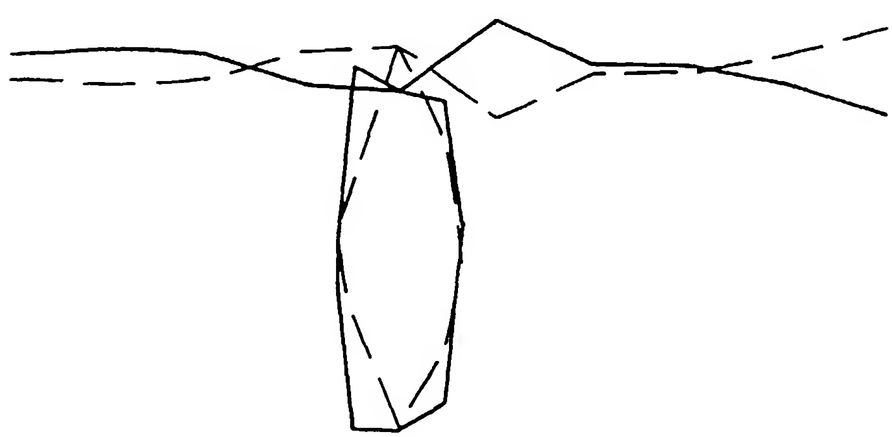


FIG.10(A)

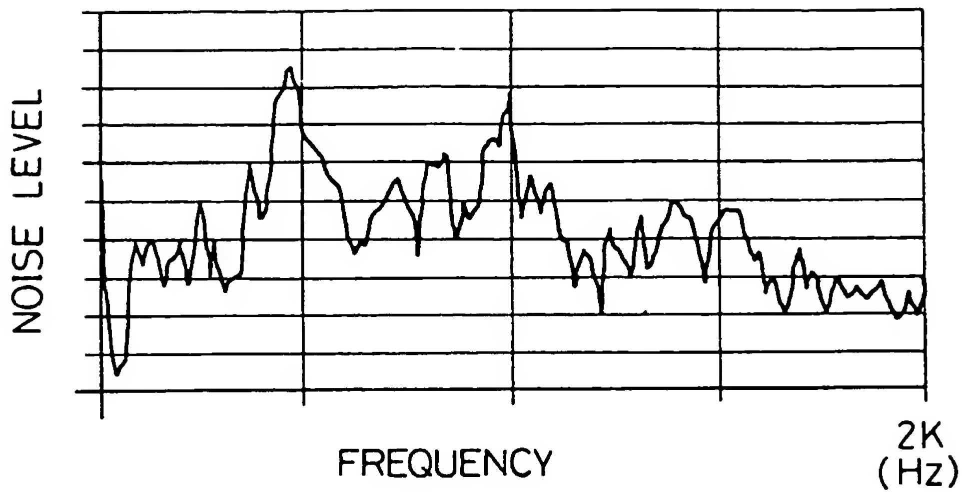


FIG.10(B)

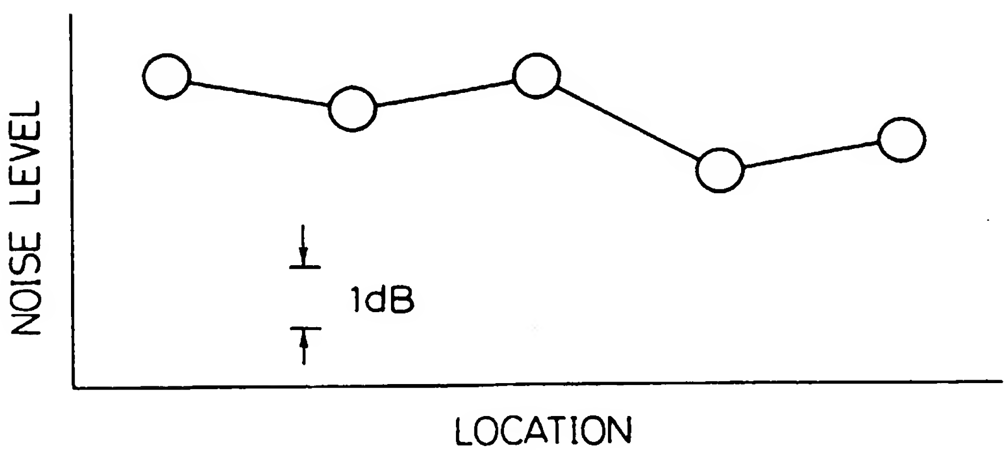


FIG.11

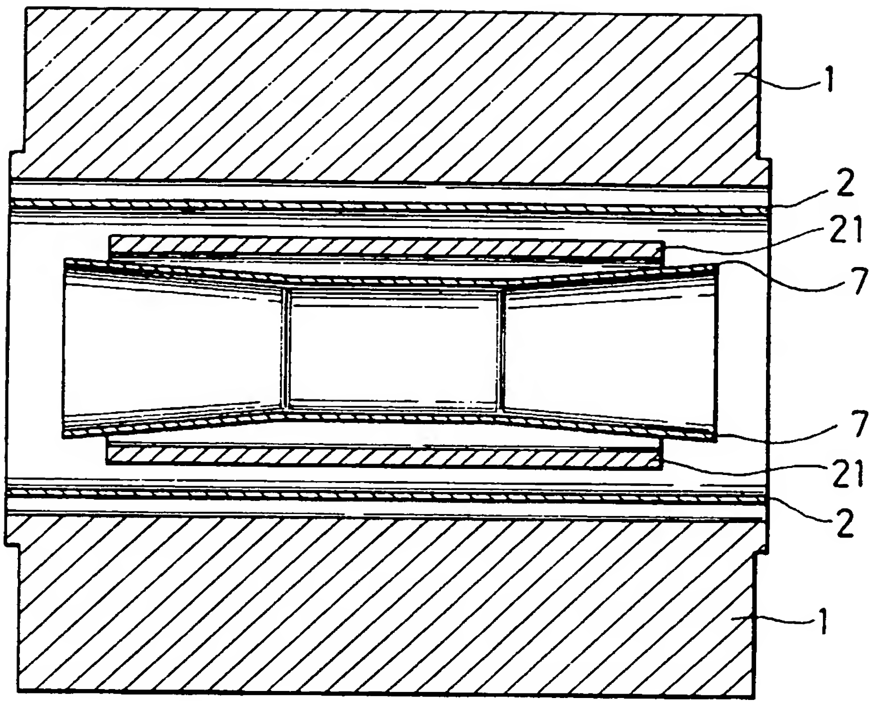


FIG.12

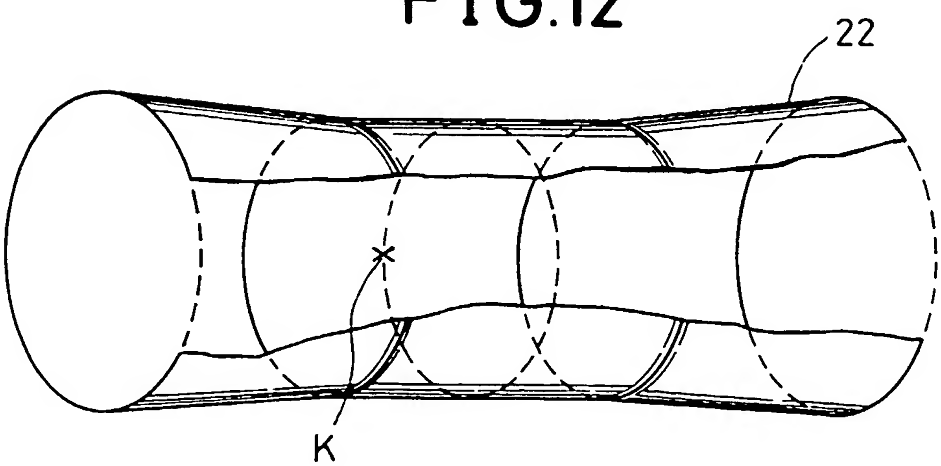


FIG.13

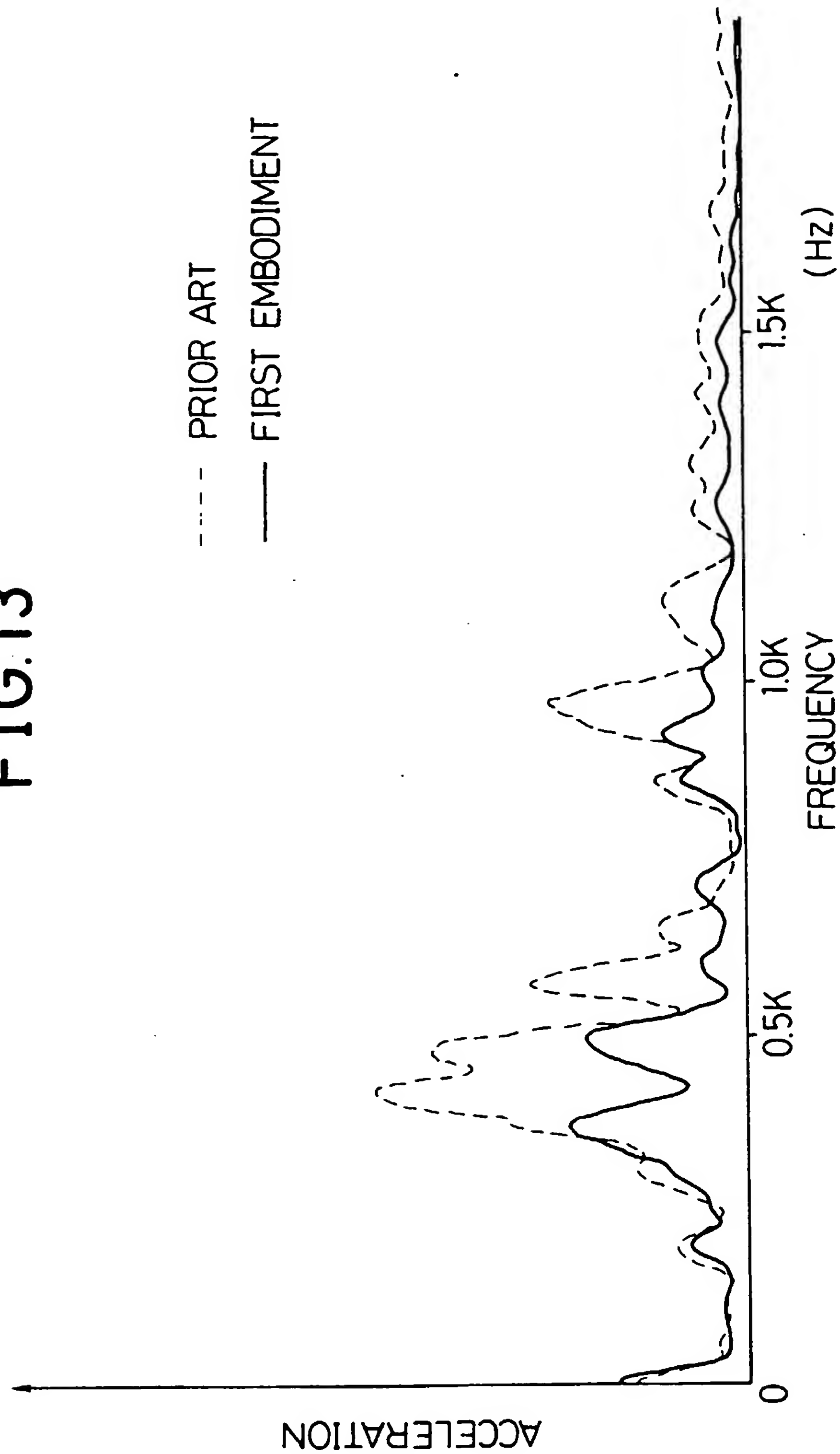

PRIOR ART
FIRST EMBODIMENT
ACCELERATION
0
0.5K
1.0K
1.5K
(Hz)
FREQUENCY

FIG.14

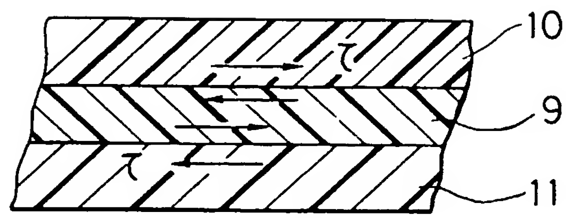

10
9
11

FIG.15

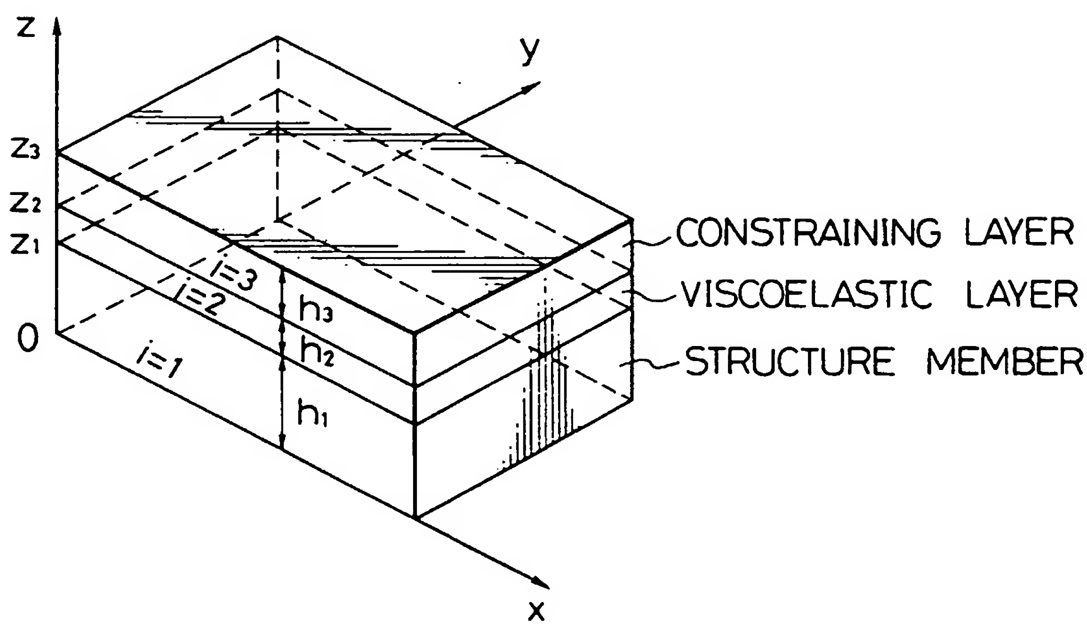

z
y
x
z3
z2
z1
0
i=3
i=2
i=1
h3
h2
h1
CONSTRAINING LAYER
VISCOELASTIC LAYER
STRUCTURE MEMBER

FIG.16

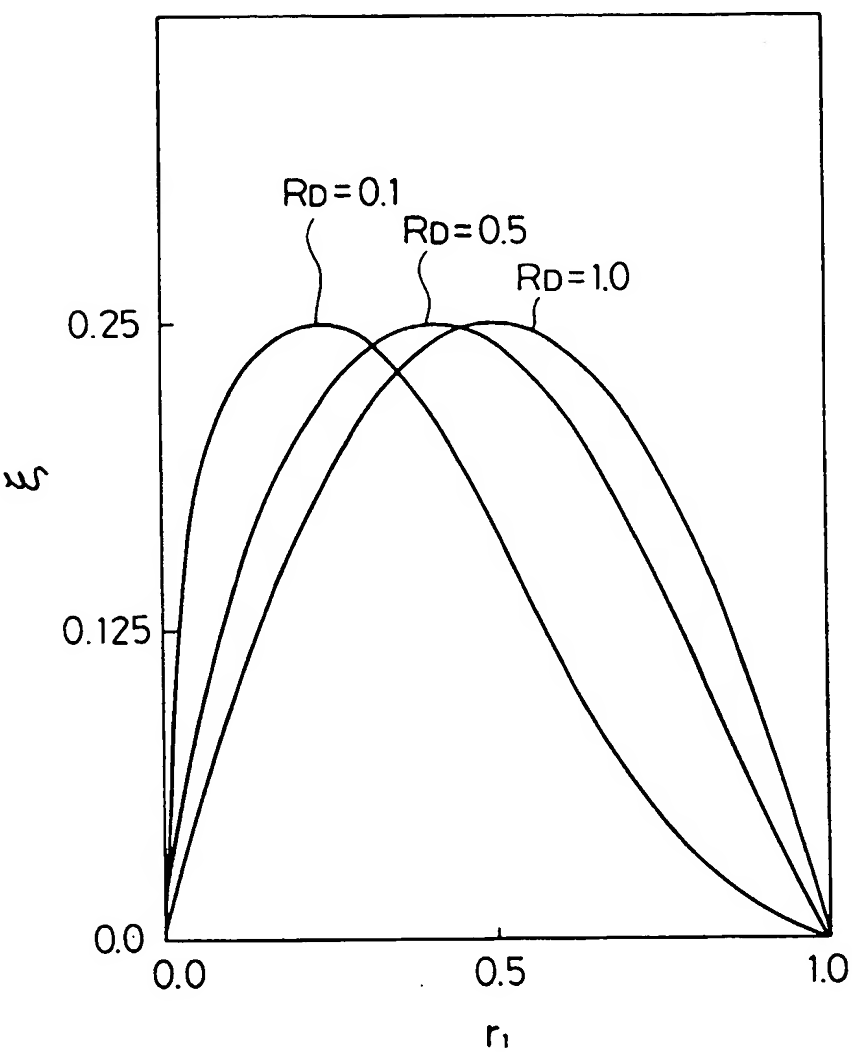


FIG.17

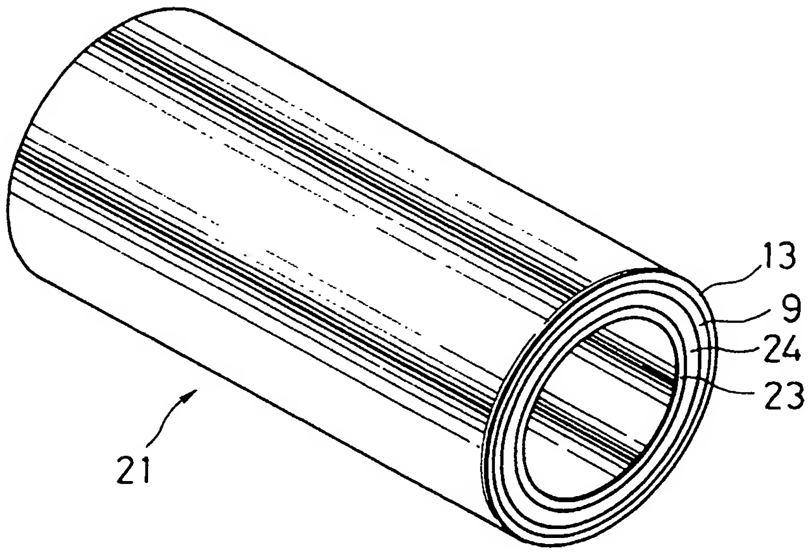


FIG.18

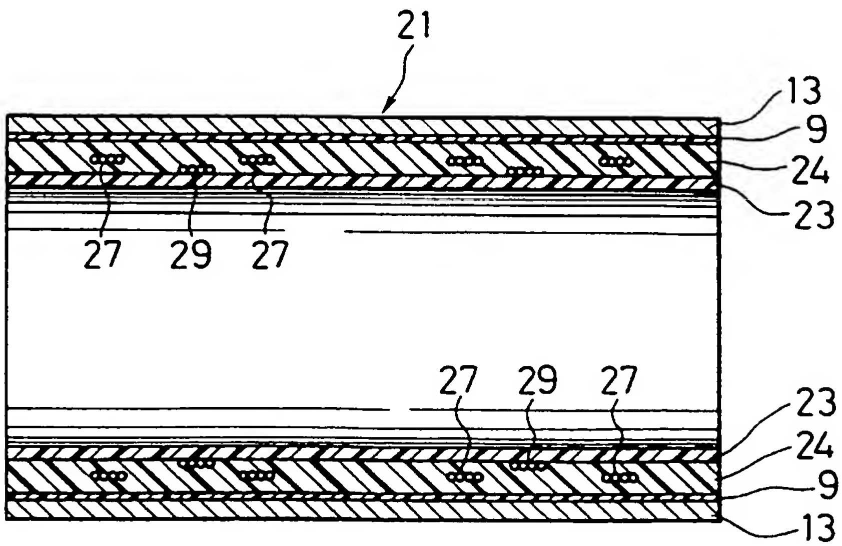


FIG.19

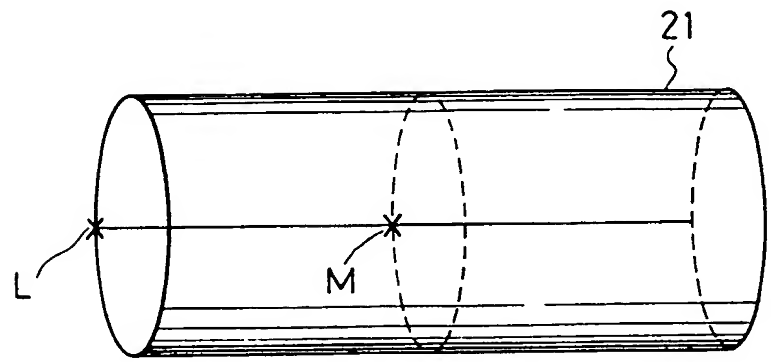


FIG.20

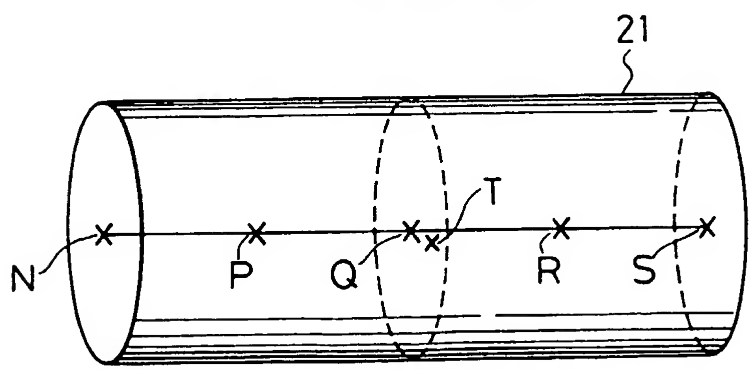


FIG.21

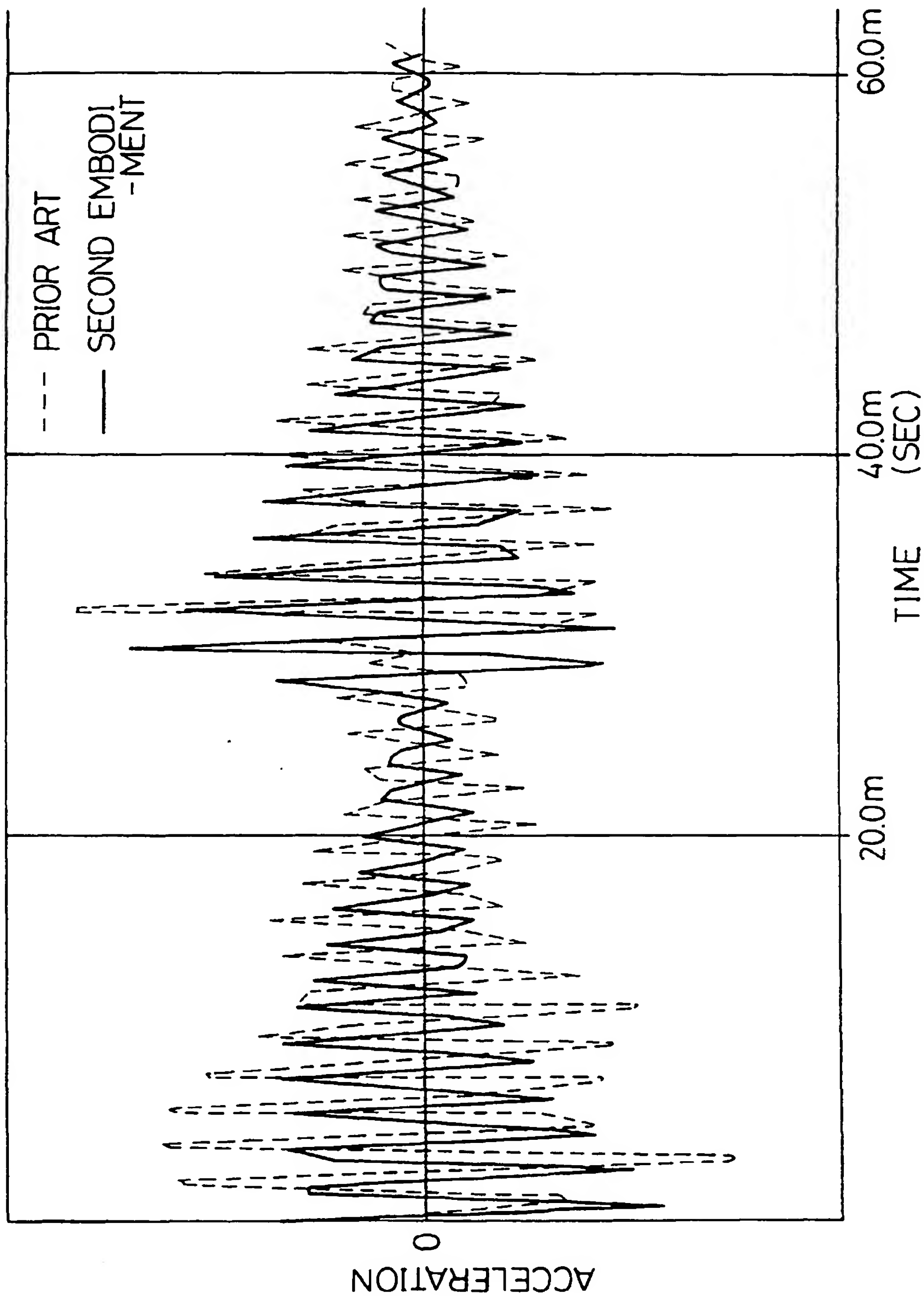
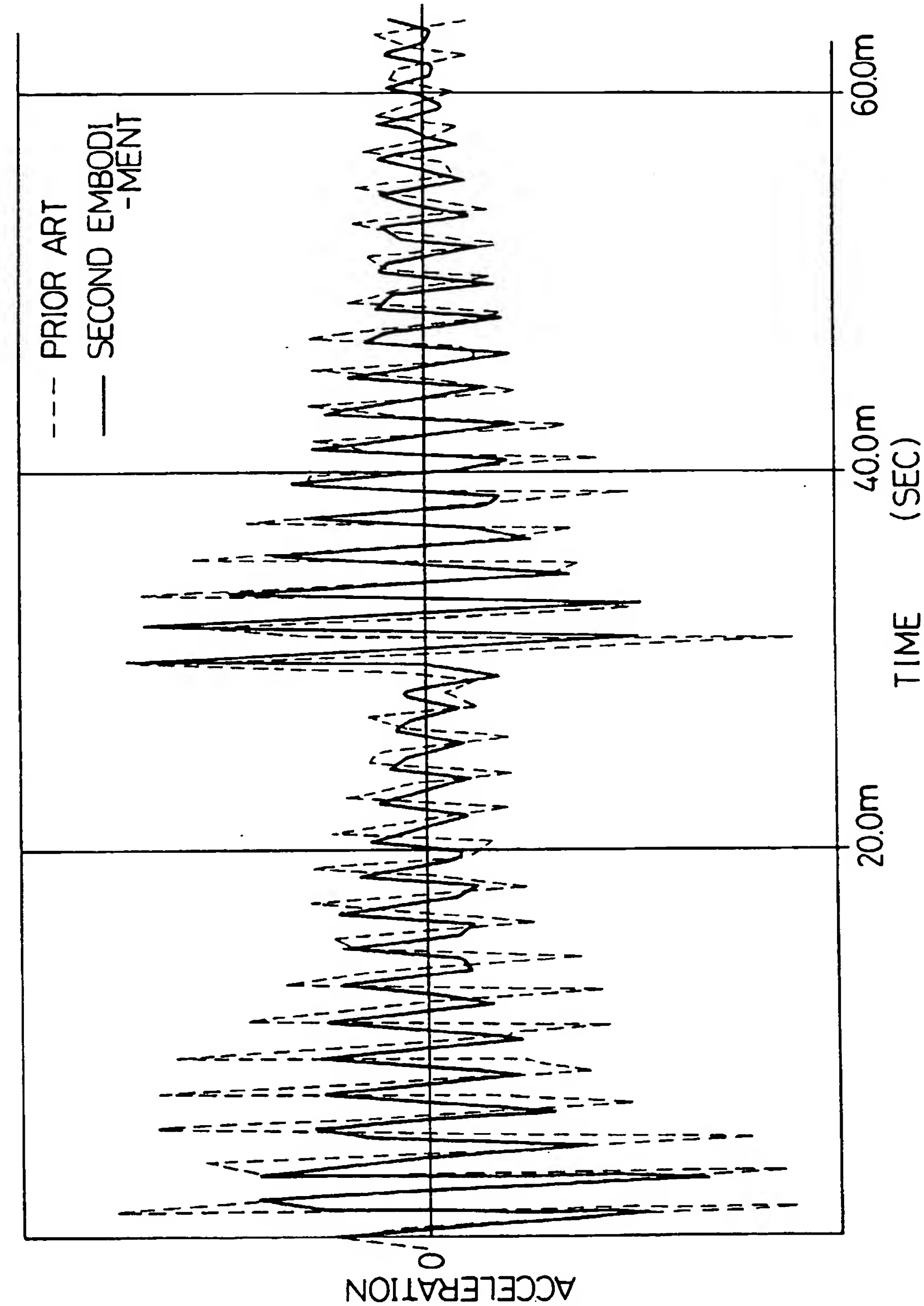

PRIOR ART
SECOND EMBODI-MENT
ACCELERATION
0
20.0m
40.0m
60.0m
TIME (SEC)

FIG.22



PRIOR ART
SECOND EMBODI-MENT
ACCELERATION
0
20.0m
40.0m
60.0m
TIME (SEC)

FIG. 23

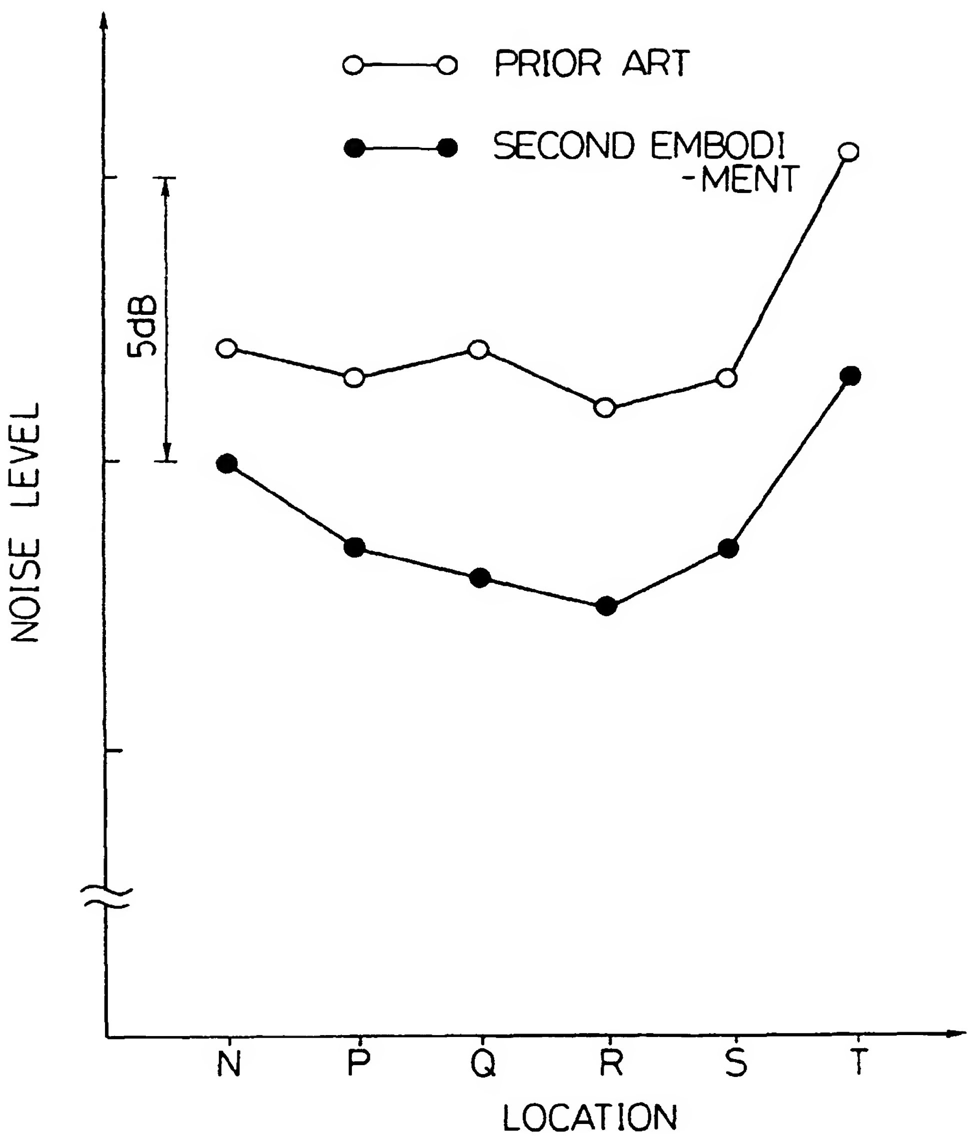

PRIOR ART
SECOND EMBODI-MENT
5dB
NOISE LEVEL
N
P
Q
R
S
T
LOCATION

FIG. 24

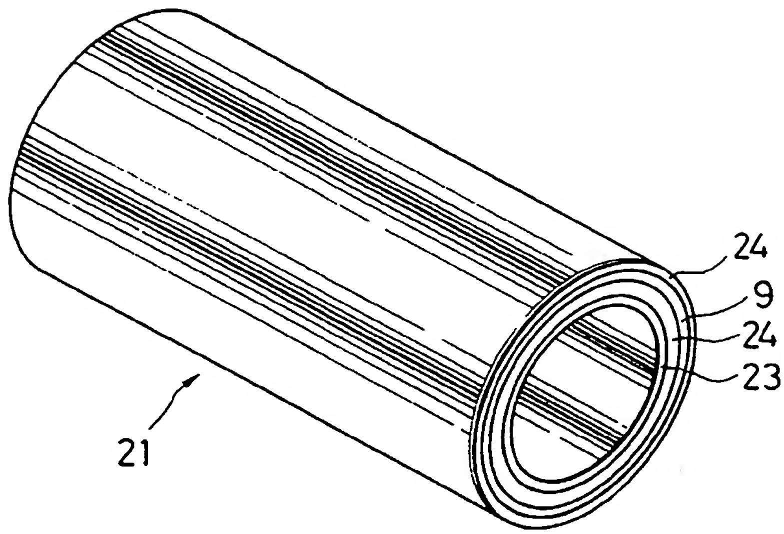


FIG. 25

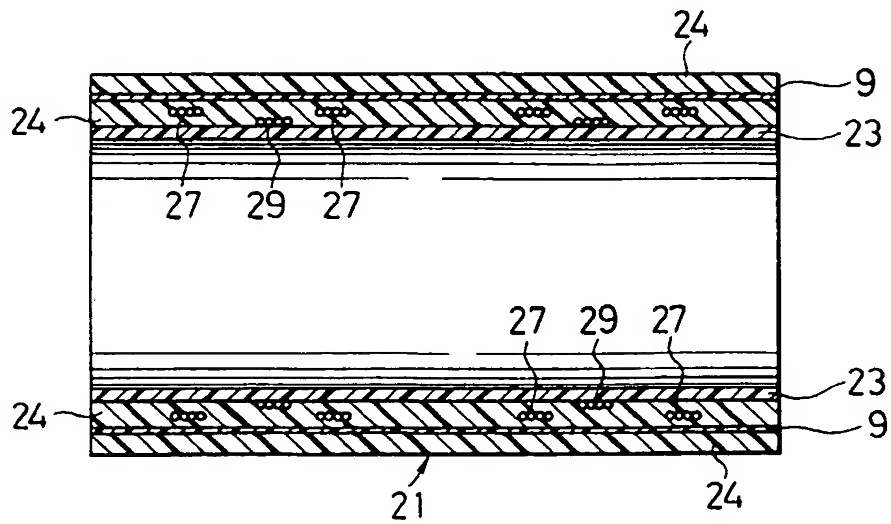


FIG. 26

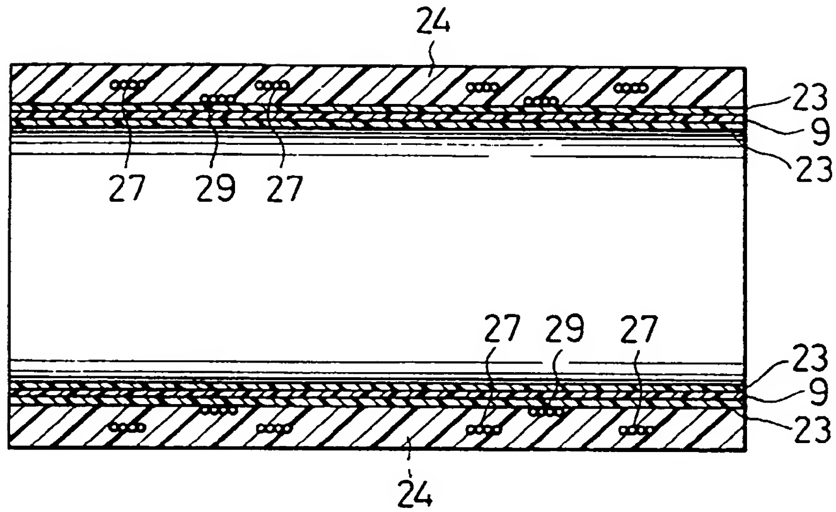


FIG. 27

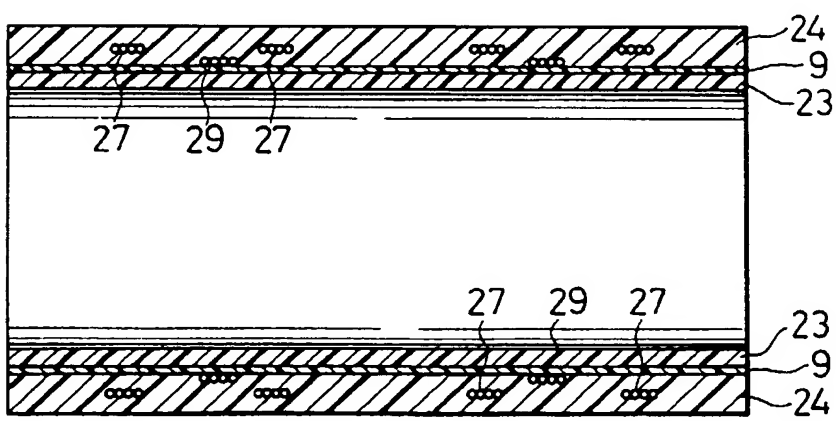


FIG. 28